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Gilbert Wittlin, et al

Lockheed-California Company

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EXPERIMENTAL PROGRAM FOR THE DEVELOPMENT OF IMPROVED HELICOPTER STRUCTURAL CRASHWORTHINESS ANALYTICAL AND DESIGN TECHNIQUES

VOLUME II

TEST DATA AND DESCRIPTION OF AN UNSYMMETRICAL CRASH ANALYSIS COMPUTER PROGRAM, INCLUDING A USER'S GUIDE AND SAMPLE CASE

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FORT EUSTIS, VIRGINIA

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Volume II contains supporting data for the details presented in Volume I. ~~This volume~~ contains abstracts for the 32 technical reports reviewed during the program. Included in the literature survey section is a matrix categorization of the reports by subject and applicable areas of interest. A brief description is presented on STAGS, the LMSC computer program used to perform the analysis of the P2V-4 fuselage bumper. A comprehensive description of program KRASH is presented, including the theory, initial conditions, the User's Guide, and a sample problem. Twenty-six channels of recorded test data and film data are presented in another section. Additional analytical data are presented in the last section.

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	ROLE	WT	ROLE	WT	ROLE	WT
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analytical techniques						
experimental program						
accident analysis						
human tolerance						
survivable accident						
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This report was prepared by Lockheed-California Company under the terms of Contract DAAJ02-71-C-0066. The Eustis Directorate technical monitor for this effort was Mr. G. T. Singley III of the Military Operations Technology Division.

The purpose of this effort was to develop (1) a computerized mathematical simulation which can predict the dynamic response of U.S. Army helicopters exposed to a crash environment with combined vertical and lateral impact velocity components, and (2) design techniques which, when implemented, will enhance occupant survival and reduce materiel losses during severe yet survivable helicopter accidents. The contractor achieved these objectives by (1) conducting literature, accident data, and organizational surveys, (2) developing a 40-mass, 240-degree-of-freedom, nonlinear lumped mass mathematical model, (3) tailoring the model to represent the UH-1D/H aircraft, (4) correlating the computerized UH-1D/H mathematical model with the results of a full-scale UH-1D/H drop test, and (5) conducting parametric studies to analyze the effect of design changes on system crashworthiness. This report contains a description of the state-of-the-art surveys, mathematical model, parametric studies, supporting testing, and results obtained.

The conclusions and recommendations submitted by the contractor are considered to be valid.

The report is divided into two volumes. Volume I contains a description of the state-of-the-art surveys, mathematical model, testing, parametric study, and results obtained. Volume II contains abstracts of literature reviewed, a comprehensive description of the mathematical model, a user's guide for the computer program, and the full-scale crash test instrumentation and photographic data.

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SUMMARY

Volume II contains supporting data for the details presented in Volume I. This volume contains abstracts for the 32 technical reports reviewed during the program. Included in the literature survey section is a matrix categorization of the reports by subject and applicable areas of interest. A brief description is presented on STAGS, the LMSC computer program used to perform the analysis of the P2V-4 fuselage bumper. A comprehensive description of program KRASH is presented, including the theory, initial conditions, the User's Guide, and a sample problem. Twenty-six channels of recorded test data, 13 channels of filtered data, and 48 channels of integrated test data and film data are presented in another section. Additional analytical data are presented in the last section.

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LIST OF SYMBOLS

MATHEMATICAL MODEL

A_i, B_i, C_i	Terms used in Euler's equations of motion (68)
$[A_i]$	Rotation transformation matrix from body axes to ground axes
$[\bar{A}_i]$	Matrix relating $(\dot{\phi}_i, \dot{\theta}_i, \dot{\psi}_i)$ to (p_i, q_i, r_i) in equation (92)
$[\dot{A}_i]$	Time derivative of $[A_i]$
$[A_i'']$	Rotation transformation matrix from ith body axes to c.g. axes
$[A_{ij}]$	Rotation transformation matrix from beam ij axes to body i axes
$[A']$	Rotation transformation matrix from c.g. axes to ground axes
$[\bar{A}']$	Matrix relating $(\dot{\phi}', \dot{\theta}', \dot{\psi}')$ to (p', q', r') in equation (88)
C_{ik}	End point of kth spring on ith mass
C'_{ik}	Ground contact point of kth spring on ith mass
dvc_{ijk}	Ground axes components of vector from m_i to C_{ik}
dvc'_{ijk}	Ground axes components of vector for C'_{ik} to C_{ik}
$[D_i]$	Derivative matrix used in equation (2)
$[D']$	Derivative matrix used in equation (86)
FM_{ijkl}	Running time sum of ΔFM_{ijkl}
$\overline{FM}_{ijkl}$	Value of FM_{ijkl} at time of loading reversal
FSP_{ijk}	Body i axes components of spring force at ground contact point C'_{ik}
$FSPO_{ik}$	Axial compressive force in kth spring on ith mass
$\overline{FSPO}_{ik}$	Value of $FSPO_{ik}$ at time of loading reversal

LIST OF SYMBOLS

MATHEMATICAL MODEL

$FSPO_{Fik}$	Final value of $FSPO_{ik}$ in input table of s_{ik} vs. $FSPO_{ik}$
G	Center-of-gravity of total vehicle
H	Origin of helicopter coordinate system (F.S.0, B.L.0, W.L.0)
He_{xi}, He_{yi}, He_{zi}	Angular momenta of mi due to rotation of masses internal to m_i
I_{xi}, I_{yi}, I_{zi}	Moments of inertia of lumped mass mi, about ith body fixed axes
I_{xyi}, I_{yzi}, I_{zxi}	Products of inertia of lumped mass m_i, about ith body fixed axes
ke_{ik}	Linear unloading stiffness for kth spring
$[K_{ij}]$	Six by six linear stiffness matrix for beam ij
$[KR_{ij}]$	Six by six diagonal stiffness reduction metrix for beam ij.
l_{ik}	Length of vector from m_i to ground contact point C'_{ik}
$\bar{l}_{xi}$, $\bar{l}_{yi}$, $\bar{l}_{zi}(\bar{l}_{ik})$	Free length of kth spring on ith mass
l_{ci}	Aerodynamic lift constant
$LIFT_i$	Aerodynamic lift on m_i, positive up, in ground axes
m_i	ith lumped mass
mu_{ik}	Ground-spring friction coefficient for kth spring on ith mass
N	Total number of lumped masses
$\bar{n}_{ik}$	Unit vector triad fixed in ith body coordinate system
$\bar{n}_x$, $\bar{n}_y$, $\bar{n}_z$	Unit vector triad fixed in ground coordinate system
O	Origin of ground coordinate system

LIST OF SYMBOLS

MATHEMATICAL MODEL

p_i, q_i, r_i	ith body axes components of absolute angular velocity vector of mass i
p', q', r'	c.g. axes components of initial(t=0) vehicle angular velocity vector
$[pl_i]$	Contact point velocity matrix used in equation (60)
s_{ik}	Axial external spring compression, kth spring on ith mass
$\bar{s}_{ik}$	Value of s_{ik} at time of loading reversal
sF_{ik}	Final value of s_{ik} in input table of s_{ik} vs. $FSPO_{ik}$
s_{ik}	kth spring axial compression measured relative to current load stroke curve origin
s''_{ik}	Horizontal shift of s'_{ik} coordinates with respect to S_{ik} coordinates
t	Time
$[T_{ij}]$	Static balance matrix used in equation (30b)
u_i, v_i, w_i	Body i axes components of absolute translational velocity vector of point m_i
va_{ij}	x_i, y_i, z_i
vb_{ij}	Running time sum of Δvb_{ij}
$\overline{vb}_{ijl}$	Value of vb_{ijl} at time of loading reversal
$\bar{V}_{ik}$	Magnitude of ground plane contact point velocity
vb'_{ijl}	lth total beam deflection measured relative to current load-stroke curve origin
vb''_{ijl}	Horizontal shift of vb'_{ijl} coordinates with respect to vb_{ijl} coordinates
vc_{ijk}	Ground coordinates of point C_{ik}

LIST OF SYMBOLS

MATHEMATICAL MODEL

$v\dot{c}p_{ijk}$	Ground axes components of absolute velocity of ground contact point C'_{ik}
${}^{m_i}\overrightarrow{V}^{c'}$	Velocity vector of C'_{ik} with respect to m_i
${}^{o}\overrightarrow{V}^{c'}$	Velocity vector of C'_{ik} with respect to ground
${}^{o}\overrightarrow{V}^{m_i}$	Velocity vector of m_i with respect to ground
W_i	Weight of ith lumped mass
W_{TOT}	Total vehicle weight
$xb_{ij}, yb_{ij}, zb_{ij}$	Beam ij coordinates
$x_G, y_G, z_G\ (vg_j)$	Ground coordinates of initial (t = o) c.g. position
$\dot{x}_G, \dot{y}_G, \dot{z}_G$	Ground axes components of initial (t = o) c.g. velocity vector
$x''_G, y''_G, z''_G\ (vgpp_{ij})$	Helicopter axes coordinates of vehicle c.g. (point G)
$x_i, y_i, z_i\ (vm_{ij})$	Ground coordinates of m_i
$x'_i, y'_i, z'_i\ (vip_{ij})$	Coordinates of m_i in center-of-gravity coordinate system
$x''_i, y''_i, z''_i\ (vipp_{ij})$	Coordinates of m_i in helicopter coordinate system
x_{ij}, y_{ij}, z_{ij}	Ground coordinates of vector from point i to point j
$x'_{ij}, y'_{ij}, z'_{ij}$	ith body coordinates of vector from point i to point j
$\begin{pmatrix} X'_{ij}, & Y'_{ij}, & Z'_{ij} \\ L'_{ij}, & M'_{ij}, & N'_{ij} \end{pmatrix}_o$	Total (summed over time) internal forces and moments at point i due to beam ij, body i axes
$\begin{pmatrix} X'_{ji}, & Y'_{ji}, & Z'_{ji} \\ L'_{ji}, & M'_{ji}, & N'_{ji} \end{pmatrix}$	Total (summed over time) internal forces and moments at point j due to beam ij, body j axes

LIST OF SYMBOLS

MATHEMATICAL MODEL

$\begin{pmatrix} X_i, & Y_i, & Z_i \\ L_i, & M_i, & N_i \end{pmatrix}$	Total forces and moments on mass i, in ith body axes
X_{Ai} Y_{Ai}, Z_{Ai}	Aerodynamic forces, body i axes
$\begin{pmatrix} X_{Ci}, & Y_{Ci}, & Z_{Ci} \\ L_{Ci}, & M_{Ci}, & N_{Ci} \end{pmatrix}$	Crash (external) forces and moments, body i axes
X_{Gi}, Y_{Gi}, Z_{Gi}	Gravity forces, body i axes
$\begin{pmatrix} X_{Ii}, & Y_{Ii}, & Z_{Ii} \\ L_{Ii}, & M_{Ii}, & N_{Ii} \end{pmatrix}$	Internal forces and moments, body i axes
$XVOC_{ijk}$	Ground axes components of spring force at ground contact point C'_{ik}, positive up, left and aft
zc_{MAX}	Vertical distance from c.g. to lowest C'_{ik}
Δ_i	Determinate expression used in equation (68)
ΔF_{ijk}	Incremental forces and moments at point j due to beam ij
ΔFM_{ijkl}	kth incremental load due to lth incremental deflection for beam ij
$\Delta\phi b_{ij}$, $\Delta\theta b_{ij}$, $\Delta\psi b_{ij}$	Incremental rotations of point j with respect to point i, in beam ij axes
$\Delta\phi_i$, $\Delta\theta_i$, $\Delta\psi_i$	Incremental change in ith mass Euler angles
Δt	Numerical integration time interval
Δvb_{ij}	Six element vector made up of Δxb_{ij}, Δyb_{ij}, Δzb_{ij}, $\Delta\phi b_{ij}$, $\Delta\theta b_{ij}$, $\Delta\psi b_{ij}$
$\overrightarrow{\Delta vb_{ij}}$	Incremental displacement vector of point j with respect to point i, due to deformation of beam ij
$\overrightarrow{\Delta vd_{ij}}$	Incremental displacement vector of point j with respect to point i

LIST OF SYMBOLS

MATHEMATICAL MODEL

$\overrightarrow{\Delta vr}_{ij}$	Incremental displacement vector of point j with respect to point i, due to rotation of mass i
$\Delta xb_{ij}, \Delta yb_{ij}, \Delta zb_{ij}$	Coordinates of $\overrightarrow{\Delta vb}_{ij}$ in beam ij axes
$\Delta x_i, \Delta y_i, \Delta z_i$	incremental displacement of point i, ground axes
$\Delta x_{ij}, \Delta y_{ij}, \Delta z_{ij}$	Incremental displacement of point j with respect to point i in ground axes
$\begin{pmatrix} \Delta X_{ij}, \Delta Y_{ij}, \Delta Z_{ij} \\ \Delta L_{ij}, \Delta M_{ij}, \Delta N_{ij} \end{pmatrix}$	Incremental internal forces and moments at point j due to beam ij, in beam ij axes (elements of ΔF_{ij} vector)
$\begin{pmatrix} \Delta X^o_{ij}, \Delta Y^o_{ij}, \Delta Z^o_{ij} \\ \Delta L^o_{ij}, \Delta M^o_{ij}, \Delta N^o_{ij} \end{pmatrix}$	Incremental internal forces and moments at point j due to beam ij, ground axes
$\begin{pmatrix} \overline{\Delta X^o_{ij}}, \overline{\Delta Y^o_{ij}}, \overline{\Delta Z^o_{ij}} \\ \overline{\Delta L^o_{ij}} \; \overline{\Delta M^o_{ij}} \; \overline{\Delta N^o_{ij}} \end{pmatrix}$	Incremental internal forces and moments at point i due to beam ij ,ground axes
$\begin{pmatrix} \Delta X'_{ij}, \Delta Y'_{ij}, \Delta Z'_{ij} \\ \Delta L'_{ij}, \Delta M'_{ij}, \Delta N'_{ij} \end{pmatrix}$	Incremental internal forces and moments at point i due to beam ij, body i axes
$\begin{pmatrix} \Delta X'_{ji}, \Delta Y'_{ji}, \Delta Z'_{ji} \\ \Delta L'_{ji}, \Delta M'_{ji}, \Delta N'_{ji} \end{pmatrix}$	Incremental internal forces and moments at point j due to beam ij, body j axes
ϕ_i, θ_i, ψ_i	Euler angles from ground axes to body axes (time varying)
$\phi_{ij}, \theta_{ij}, \psi_{ij}$	Euler angles from ith body axes to beam ij axes (constant)
ϕ', θ', ψ'	Euler angles from ground axes to c.g. axes (constant); initial (t=o) attitude of vehicle
$\phi''_i, \theta''_i, \psi''_i$	Euler angles from c.g. axes to ith body axes (constant)

INTRODUCTION

This report contains test and analysis data in support of the detailed discussions presented in Volume I. The format in this volume is consistent with the order of the major sections of Volume I.

The 32 technical reports and specifications reviewed during the study are briefly summarized and then tabulated in a Literature Survey Subject Index. Program STAGS is briefly described in the next section. This is followed by a comprehensive description of Program KRASH, including input and output data formats and a sample problem.

The test data is presented in the form of:

- recorded acceleration and strain gage time histories
- 100-cps low-pass filtered acceleration histories
- integrated velocity time histories
- integrated displacement time histories
- film data
- calculated test impact velocities

The analytical data consists of sample output plots obtained with program KRASH during the correlation analysis.

LITERATURE SURVEY

LITERATURE SYNOPSIS

1. Reed, William, Avery, James Ph.D., PRINCIPLES FOR IMPROVING STRUCTURAL CRASHWORTHINESS FOR STOL AND CTOL AIRCRAFT, Aviation Safety Engineering and Research; USAAVLABS Technical Report 66-39, U. S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, June 1966, AD 637133.

In this report, the area of crash behavior analysis of aircraft structures is investigated. The investigation begins with the definition of two indices of crashworthiness of basic aircraft structures and the analysis of the influence of several general types of structural modifications upon these two indices. This analysis, using fundamental principles of mechanics, contains several simplifying assumptions, which are explained as they are introduced.

Design concepts to improve the ability of the "protective container" to maintain living space for occupants during a crash or to attenuate the accelerations experienced by occupants during a crash are developed for crash conditions which are either primarily longitudinal in nature or primarily vertical in nature. Analytical methods are then provided to show how and when to apply these design concepts to any particular aircraft. Principles are presented which are considered to be suitable for use during design of new aircraft as well as modifications of existing aircraft.

The results are presented from three full-scale crash tests of small twin-engine airplanes which were conducted as a part of this investigation.

Among the pertinent conclusions of the report are: (1) improvements in crashworthiness can be achieved via minor changes in structural design or modification of existing structure, (2) vertical and longitudinal impact environments offer significantly different problems in designing for improved crashworthiness, and (3) analysis of aircraft behavior is hampered by the lack of adequate knowledge of the relationships which apply to the determination of the reaction force which decelerates the aircraft upon contact with the ground.

2. Turnbow, J. W., Carroll, D. F., Haley, J. L., Jr. Robertson, S. N. CRASH SURVIVAL DESIGN GUIDE, Dynamic Science; USAAVLABS Technical Report 70-22, U. S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, August 1969, AD 695648. (Most recent revision is USAAMRDL TR 71-22, AD 733358)

This report is a design guide that has been assembled to provide the engineer with an understanding of the basic problems associated with the development of crashworthy U. S. Army aircraft. Where possible, solutions to specific problems are indicated. In areas in which little design data are available, only the general philosophy appropriate to the problem solution is presented; the details of such solutions as well as the degree of crashworthiness to be achieved must be left, at present, to the ingenuity of the designer.

This guide presents, in a condensed form, the data, design techniques, and criteria that are presently available in eight areas: (1) aircraft crash kinematic and survival envelope, (2) airframe crashworthiness design criteria, (3) aircraft seat design criteria (crew and troop/passenger), (4) restraint system design criteria (crew, troop/passenger, and cargo), (5) occupant environment design criteria, (6) aircraft ancillary equipment stowage design criteria, (7) emergency escape provisions, and (8) postcrash fire design criteria.

It is intended that both airframe and component designers and manufacturers use this guide to extend the "region of survivability" in aircraft accidents to a maximum level.

3. Gatlin, Clifford; Goebel, Donald; and Larsen, Stuart; ANALYSIS OF HELICOPTER STRUCTURAL CRASHWORTHINESS, Dynamic Science; USAAVLABS Technical Report 70-71, Eustis Directorate U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, January 1971, AD 880680 and AD 880678.

This report describes the development of a mathematical model that will simulate the response of a UH-1D/H helicopter airframe to vertical crash loading and the full-scale crash test performed to verify the validity of the model.

In the initial phase of the model development, a study was made of 43 major accidents involving the UH-1D/H aircraft to determine what types of structural failure were contributing to injuries in helicopter accidents.

Based on the results of this accident study, a nonlinear lumped-mass model of 23 degrees of freedom was developed and programmed for computer solution. This model was then used in a parametric study of the UH-1D/H to evaluate potential areas of crashworthiness improvement.

At the conclusion of the parametric study, a full-scale, instrumented drop test of a UH-1D/H airframe was conducted. The data generated in this test were correlated with the model data to determine the ability of the model to predict airframe accelerations and deflections under crash conditions.

The results of this program indicate that:

- The structural weaknesses contributing to most impact injuries in UH-1D/H helicopter accidents are lack of resistance to failure in lateral rollover and lack of energy-absorbing capability to reduce vertical accelerations.
- The mathematical model is capable of accurately predicting the floor and engine accelerations and deflections.
- In its present form, the model does not accurately predict the transmission accelerations and deflections.

It is recommended in the report that further research in the field of mathematical modeling for structural crashworthiness be conducted.

4. Greer, D. L., et al, CRASHWORTHY DESIGN PRINCIPLES, General Dynamics, Convair; FAA Technical Report ADS-24, Federal Aviation Administration, Washington, D. C., November 1965, AD 623575.

The primary areas of study in the investigation of transport aircraft crashworthiness, presented in this report, are as follows:

- Mechanisms of failure and energy absorption structure:

  To retain habitable shell structure.

- Delethalization:

  To improve occupant retention system and occupant safety

- Evacuation:

  Structural integrity on evacuation efficiency

The study indicates that crashworthiness improvements can be realized by increased fuselage strength, redistribution of load-carrying materials in the structure, and the use of more ductile materials in local areas. It is stated in the report that no appreciable weight or cost increase is necessary to improve survivability in a transport aircraft if consideration is given to crashworthy principles at the preliminary design level.

Investigations into occupant retention and safety indicate that seat failures and occupant injuries are probably more often the result of seat and support structure design inadequacies and relative velocity between seat and occupant than of excessive airplane deceleration.

The primary parameters affect the assumptions regarding the crash environment are terrain, descent angle, impact angle and approach velocity.

Although ductility is an important property of airframe structure for crashworthiness design, it is difficult to measure. Elongation, tear resistance, crack propagation, and stress or strain concentration effects are all needed to determine the material best suited to a crashworthy design.

5. Reed, W. H., et al, FULL SCALE DYNAMIC CRASH TEST OF A DOUGLAS DC-7 AIRCRAFT, Aviation Safety Engineering and Research; FAA Technical Report ADS-37, Federal Aviation Administration, Washington, D. C., April 1965, AD 624051.

This report describes a test program designed to obtain crash environment data regarding fuel containment and to collect data on the behavior of various components and equipment aboard the aircraft using a DC-7 as the test vehicle.

The test involved a DC-7 aircraft which was guided into a series of crash barriers with a monorail nose gear guidance system. The aircraft was accelerated under its own power by remote control for a distance of 4000 feet, reaching a velocity of 110 knots. At the end of this acceleration run, the aircraft impacted against a specially designed barrier which removed the landing gear, permitting the aircraft to become airborne until the moment of impact with wing and fuselage crash barriers.

The wing and fuselage barriers were designed to provide the following crash sequence: The left wing was to impact against an earthen mound shaped to produce a simulated wing-low accident. Simultaneously, the right wing was to impact telephone poles implanted vertically to simulate trees. Next, the main fuselage was to impact against an 8-degree slope. The slope was designed so that the aircraft could become airborne after sliding a short distance along the ground. Finally the aircraft was to impact against a 20-degree slope to simulate a crash with a steeper angle of impact.

The test occurred as planned except that the aircraft, instead of coming to rest on the 20-degree slope, bounced over the hill on which the slope was formed and landed at the base of the backside of the hill. A failure of the voltage control regulator, in the data recording system, prevented the program from reaching all its objectives.

6. Reed, W. H., et al, FULL-SCALE DYNAMIC CRASH TEST OF A LOCKHEED CONSTELLATION MODEL 1649 AIRCRAFT, Aviation Safety Engineering and Research; FAA Technical Report ADS-38, Federal Aviation Administration, Washington, D. C., October 1965.

This report provides the details of a full-scale crash test of a large transport aircraft. The purpose of the test was to obtain crash environment data of the test aircraft and the various experiments installed aboard the aircraft.

The Federal Aviation Agency sponsored the test program with the participation of several other organizations who provided data recording equipment and special experiments on board the test aircraft. The participating organizations included the U. S. Navy, the U. S. Army, the U. S. Air Force, the Society of Automotive Engineers, and the Flight Safety Foundation, which conducted the test under contract to and with the guidance of the FAA. The special experiments consisted of military crew and commercial passenger seats, cargo restraint systems, postcrash locator beacons, baby and child restraint systems, radioactive material containers, a military litter system, and provisions for emergency lighting.

The test involved a Lockheed Constellation Model 1649A aircraft, which was guided into a series of crash barriers with a monorail nose gear guidance system. The aircraft was accelerated under its own power by remote control for a distance of 4,000 feet, reaching a velocity of 112 knots. Initial impact occurred against barriers which removed the landing gear, permitting the airplane to become airborne until the moment of impact with the wing and fuselage crash barriers.

The wing fuel tanks were ripped open by the wing barriers, allowing simulated fuel to spill out in a heavy mist during the crash sequence. The fuselage was broken in two places during the crash, just aft of the cockpit between fuselage stations 370 and 380 and just aft of the galley between fuselage stations 1020 and 1030. Peak longitudinal accelerations on the order of 25 G's were measured at the cockpit floor when the aircraft impacted the 20-degree slope. Most of the on-board experiments remained in their relative locations throughout the test.

7. Fitzgibbon, Donald P., et al, CRASH LOADS ENVIRONMENT STUDY, Mechanics Research, Inc.; FAA Technical Report DS-67-2, Federal Aviation Administration, Washington, D. C., February 1967, AD 655920.

This report presents a study of the survivable crash environment for commercial type aircraft. The study includes an analysis both of the results of previous crash tests of full-scale aircraft components and of the data from actual commercial aircraft crashes during the period of 1955 through 1965.

The severity of each crash test has been determined by relating the characteristics of the measured acceleration time histories to the characteristics of human tolerance to acceleration. The results of this analysis show that the severity of a crash for a given set of crash parameters is highly dependent upon the configuration, structural design, and weight of the aircraft.

The determination of the crash environment is accomplished through the use of the shock spectra of acceleration time histories from the crash tests. Shock spectra were obtained for all the pertinent acceleration time histories, and the methods determining equivalent pulses are presented. The application of this method to the specification of component test environment is discussed.

The data from actual commercial crashes is presented and analyzed. It was found that the most common survivable accident can be described as occurring during the landing phase of the flight, with null, pitch, roll and yaw angles, with an angle of impact of less than 5 degrees, and with an impact velocity of 166 feet per second. The most common obstacle encountered during the crash was trees. It was also found that there were no strong correlations between the crash parameters and the severity measured in terms of the percentage of the occupants killed.

Methods for generalizing the crash environments relative to the treatment of fuel tank locations and components attached to fuselage floor structure are presented. Idealization of the acceleration time history curves is considered to be adequate for fuel tank locations because of the large dampening effect of the fuel. For components attached to the structure, use of the shock spectra is advocated for generalizing the crash environment in order to include significant high-frequency loads in the selection of design criteria.

Based on the results of the study, the requirements for future full-scale tests are presented. The crash parameters are presented for a modern jet aircraft to produce a marginally survivable accident.

The instrumentation requirements are described and a data acquisition system is recommended.

8. Greer, D. L., et al, DESIGN STUDY AND MODEL STRUCTURES TEST PROGRAM TO IMPROVE FUSELAGE CRASHWORTHINESS, General Dynamics, Convair; FAA Report DS-67-20, Federal Aviation Administration, Washington, D. C., October 1967.

This report presents the results of a study to evaluate methods to improve crashworthiness by retaining transport cabin integrity during crash impact loadings.

The study includes analyses of the effects of strengthening, redistribution of bending material, and incorporation of energy dissipating features on the ability of the fuselage to provide a protective shell around the occupants. Analytical results were substantiated by a test program.

The test program included compression tests of plate-stringer panels and drop tests of representative fuselage structure. Tests were made on three 100-inch-diameter cylindrical sections dropped axially, four segments of 100-inch-diameter cylinders dropped laterally, and a structurally complete nose section of a jet transport dropped in a 10-degree nose-down attitude.

The requirement for a plastically deforming structure is important for both axial and vertical collapse characteristics of a fuselage. Plastic collapse provides the most efficient energy-absorbing capability and also reduces the possibility of excessive tearing or complete disintegration of the structure.

The portion of the longitudinal kinetic energy that can be absorbed by structural crushing is not a significant part of the energy produced at the existing takeoff and landing speeds.

Both energy-absorbing capacity and failure mode are important for vertical crushing conditions. The recommended manner of reinforcement for the fuselage lower frame segments strengthens the bottom centerline portion and the floor beam to frame area. No significant weight or cost penalty is involved since the crash requirement reinforcement occurs at the most critical areas for existing design conditions.

An analytical approach, using a digital computer program to simulate the response of fuselage impact, is included. The mathematical model for this program consists of a beam with 10 mass items to represent the fuselage. Each mass is supported on a variable, partially restoring spring to simulate the vertical crushing characteristics of the lower fuselage structure. This analysis indicates that fuselage bending strength is of primary concern in crashworthy considerations.

9. Bigham, James P., and Bingham, William W., THEORETICAL DETERMINATION OF CRASH LOADS FOR A LOCKHEED 1649 AIRCRAFT IN A CRASH TEST PROGRAM, Boeing Airplane Company; FAA Technical Report ADS-15, Federal Aviation Administration, Washington, D. C., July 1964.

This report presents the results of an analytical study to theoretically predict the loads to be experienced by a Lockheed Model 1649 Super Constellation during a controlled crash. Acceleration time histories in directions normal and parallel to the fuselage cabin floor are given at three positions along the length of the fuselage for impact velocities of 140, 160, 180, and 200 feet per second. Results of investigations of the effects of variations in important problem parameters are also presented.

It is concluded that during the initial impact at 180 feet per second, peak normal accelerations of 11, 0, and -3 times that of gravity (G's) will be developed 0.03 second after impact at Body Stations 180, 682, and 1176. Maximum normal and longitudinal accelerations during the 6-degree ramp crash will occur at 0.24 second. Maximum normal accelerations at Body Stations 180, 682, and 1176 will be -17, 8, and 35 G's, respectively. Maximum longitudinal accelerations will be 4 G's.

It is further concluded that the nose of the airplane will bend upward 10 inches relative to the center section of the fuselage 0.14 second after impact. This deflection will probably be of sufficient magnitude to exceed the ultimate strength of the fuselage above the cabin floor. If the fuselage should fail, all analytical results beyond the time of failure will be questionable to a degree dependent on the type of failure that occurs.

10. Turnbow, J. W., Ph.D., A DYNAMIC TEST OF AN H-25 HELICOPTER, Aviation Crash Injury Research Division; SAE Report 517A, National Aeronautic Meeting, April 1962.

This paper describes the first test conducted as an exploratory study to (1) provide a "first" look at the acceleration environment in helicopter accidents and (2) evaluate certain problems inherent in the dynamic crash testing of full-scale helicopter and VTOL aircraft.

An H-25A Piasecki helicopter was employed in recreating a "typical" accident occurring with both longitudinal and vertical velocity components at impact. Acceleration patterns at various stations in the aircraft and in the dummy occupants were found to be incomparable with the results of similar tests conducted for fixed-wing aircraft by NACA. For the helicopter, large-magnitude, short-duration accelerations were observed. By contrast, accelerations of smaller magnitude but with relatively longer duration were found for transport-type aircraft by NACA. When the acceleration environment for the H-25 is compared with known tolerance limits for human subjects, evidence of the need for modification in crew and passenger seats to provide better crash protection for the aircraft's occupants becomes apparent.

11. Leredaht, B. H., et al, SOME NOTES ON THE PHYSIOLOGICAL TOLERANCE TO ACCELERATION, Douglas Aircraft Company, Report ES 40253, February 1961.

This report presents a compilation of data concerning human and animal tolerance to acceleration. Longitudinal and transverse accelerations, both positive and negative, are covered. The effects of rate and duration of acceleration are discussed.

12. Stech, Ernest, and Payne, Peter, DYNAMIC MODELS OF THE HUMAN BODY, Frost Engineering Development Company; AMRL-TR-66-157, Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio, November 1969, AD 701 383.

This report covers the analytical modeling of the human body as a single-degree-of-freedom system. Sources of body dynamic data include drop tests, sled tests, vibration tests, structural tests, animal tests, accident data and ejection seat data. Estimates of human body mass and spring stiffness, natural frequency, damping, and critical force levels are included. The effect of age on natural frequency and critical forces is estimated, as is the nonlinearity of the spinal column.

13. PERSONNEL RESTRAINT SYSTEMS STUDY, BASIC CONCEPTS, Flight Safety Foundation; TCREC Technical Report 62-94, Task 9R95-20-001-01, U.S. Army Transportation Research Command, Fort Eustis, Virginia, December 1962.

This report covers the basic concepts, applicable to all U. S. Army aircraft, that are pertinent to a personnel restraint system study. Man's limits of tolerance to decelerative loads are reviewed and related to the existing restraint harnesses currently being used in Army aircraft. The magnitude of decelerative loads to which airframes of various aircraft have been dynamically tested, while still maintaining a livable volume in the cabin, is also reviewed, and it is noted that man's limits are, in general, higher than airframe limits.

Several practical harness configurations are discussed, the load distribution between the various components of the harness is explored, and design strength values are recommended. The dynamic strength of restraint systems is also discussed and related to the static strength.

14. Coleman, Rolf R., THE MECHANICAL IMPEDANCE OF THE HUMAN BODY IN SITTING AND STANDING POSITION AT LOW FREQUENCIES, Biomedical Laboratory; ASD technical Report 61-492, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio, September 1961.

This report discusses the application of the theory of the mechanical impedance of systems with one or more degrees of freedom to the human body. A method of measuring mechanical impedance and determining the parameters of the vibrating systems is developed. Impedance curves for longitudinal vibrations of a sitting and standing subject are established for the frequency range of 1 to 20 cps. The influence of varied posture and restraining systems is investigated. Dynamic movements of body parts are measured, directly or indirectly, and compared with the impedance curves. The responsible elements in the body for the apparent resonances are identified. Correlations between the impedance function of the body and the subjective tolerance curve to vibration are found, and the reasons for the tolerance limits are explained. The variability of subjective tolerances due to varying posture, restraining systems, cushions, duration of exposure, and vibrations is discussed, and conclusions for the development of protective devices are drawn. The correlation between the steady-state response of the human body system and the effects of impact is discussed.

15. Eiband, Martin A., HUMAN TOLERANCE TO RAPIDLY APPLIED ACCELERATIONS: A SUMMARY OF THE LITERATURE, Lewis Research Center, NASA Memo 5-19-59E, National Aeronautics and Space Administration, Washington, D. C., June 1959.

The report describes a survey of the literature to determine human tolerance to rapidly applied accelerations. Pertinent human and animal experiments applicable to space flight and to crash impact forces are analyzed and discussed. These data are compared and presented on the basis of a trapezoidal pulse. The effects of body restraint and of acceleration direction, onset rate, and plateau duration on the maximum tolerable and survivable rapidly applied accelerations are shown.

Results of the survey indicate that adequate torso and extremity restraint is the primary variable in tolerance to rapidly applied accelerations. The harness, or restraint system, must be arranged to transmit the major portion of the accelerating force directly to the pelvic structure and not via the vertebral column. When the conditions of adequate restraint have been met, then the other variables -- direction, magnitude, and onset rate of rapidly applied accelerations -- govern maximum tolerance and injury limits.

The results also indicate that adequately stressed aft-facing passenger seats offer maximum complete body support with minimum objectionable harnessing. Such a seat, whether designed for 20-, 30-, or 40-G dynamic loading, would include lap strap, chest (axillary) strap, and winged-back seat to increase headward and lateral G protection, full-height integral head rest, arm rests (load-bearing) with recessed handholds and provisions to prevent arms from slipping either laterally or beyond the seat back, and leg support to keep the legs from being wedged under the seat.

For crew members and others whose duties require forward-facing seats, maximum complete body support requires lap, shoulder, and thigh straps, lap-belt tie-down strap, and full-height seat back with integral head support.

16. O'Bryan, Thomas, and Hatch, Howard, Jr., LIMITED INVESTIGATION OF CRUSHABLE STRUCTURES FOR ACCELERATION PROTECTION OF OCCUPANTS OF VEHICLES AT LOW IMPACT SPEEDS, Langley Research Center, NASA-TN-D-158, National Aeronautics and Space Administration, Washington, D.C., October 1959.

The report describes the results of a limited investigation to determine the characteristics of three materials to see how they can be applied for human protection against accelerations encountered at low impact speeds. As a result, if given man's physiological tolerance to abrupt acceleration, which has not yet been well defined, an alleviation system can be designed.

Foamed plastics require considerable depth to provide a given stopping distance for impact alleviation, and their use would require some control of rebound. They can be made soft enough to obtain the low onset of acceleration that may be necessary for man where depth is not limited.

Aluminum honeycomb is an efficient material for impact load alleviation from the standpoint of usable material depth, and it exhibits very little rebound. The stiffness of the material results in a very high initial onset rate of acceleration. For many installations, this can be controlled by reducing the initial loading area of contact to get the material to start failing.

17. UH-1 ACCIDENT SUMMARY, USABAAR Report, U. S. Army Board for Aviation Accident Research, Ft. Rucker, Alabama, 1963.

The report contains a summary of all Army UH-1 accident, incident, and forced-landing experiences for the 5-year period ending 27 September 1963. Percentage pie charts for major and minor accidents, incidents, and forced landings are given in percentages of total cause factors and are not directly related to the total number of mishaps in each category, as these mishaps often involve multiple cause factors.

Except for forced landings, pilot cause factors account for the giant's share of each pie chart. This points to a need for greater quality control in personnel selection, training, and supervision.

It is noted that many incidents and forced landings are recorded in this summary with cause factors not reported. This results from reporting units failing to provide supplemental information as it becomes available. Reports of this nature, without supplemental data, are of little use to the aviation safety program.

18. Mattox, Kenneth L., INJURY EXPERIENCE IN ARMY HELICOPTER ACCIDENTS, U. S. Army Board for Aviation Accident Research, Ft. Rucker, Alabama, September 1967, AD 658079.

The gross pattern of injury site, frequency, and seriousness in U. S. Army helicopter accidents is presented in this report. Although 95 percent of the major helicopter accidents are survivable, 22 percent of the deaths in all helicopter accidents occur under survivable conditions. The mechanisms of these avoidable deaths are discussed as well as the steps that should be taken to reduce the morbidity and mortality rate.

Correlation of accidents in Army helicopter experience to injuries incurred in them requires an analysis of the operational envelope. Most U. S. Army aircraft fly in and out of confined areas at relatively slow speed and low altitudes. Operational areas are frequently complicated by wires, tires, towers, and rough terrain at the landing site. Helicopters are not equipped with ejection seats, and because of the altitudes and missions flown, parachutes are not worn by the aviators. U. S. Army helicopters operate in an environment that nears the extreme both in density of traffic and operational terrain (versus commercial airlines flying in and out of London International). Therefore, although the helicopter has the capability to autorotate in case of in-flight emergency, the aviator must always ride the helicopter in.

19. Turnbow, James W., and Haley, J. L., Jr., A REVIEW OF CRASHWORTHY SEAT DESIGN PRINCIPLES, Arizona State University and AVSER Flight Safety Foundation, SAE Paper 851A, Air Transport and Space Meeting, April 1964.

This paper briefly reviews the known factors pertinent to the design of crashworthy aircraft seats. Ultimate design load factors, based upon human tolerance to decelerative load and the anticipated loads in accident situations for fixed-wing transport aircraft, light fixed-wing aircraft, and military helicopters are presented. The use of energy-absorbing devices is discussed. In this paper it is concluded that energy absorbers would not be practical to reduce longitudinal acceleration levels involving large velocity changes in a single deceleration pulse. However, it is deemed possible to provide energy absorption to limit vertical accelerations to the order of 20 to 25 G's in accidents occurring at rates of 50 to 50 fps, assuming some vertical deformation of the structure.

20. Rich, M. J., VULNERABILITY AND CRASHWORTHINESS IN THE DESIGN OF ROTARY WING VEHICLE STRUCTURES, SAE Paper 680673, 1968.

This paper indicates that the problem of crash survivability capability resolves to the following areas of considerations:

- Absorption of the forward velocities through ground friction and structural elastic/plastic structural energy.
- Absorption of the vertical impact through elastic/plastic structural energy.
- Provision of local strength and living space for the occupants.

The paper states that the 95th percentile potentially survivable accident environment (vertical = 47 fps, horizontal = 60 fps, lateral = 25 fps) appears to be a rational and conservative criterion. The 95th percentile crash acceleration data appears to be potentially within human tolerance limits. Peak loads, however, are very dependent on the amount of substructure to absorb the crash. Significant improvements can be achieved by considering the failure modes such that living space for survival is provided. This report also discusses the use of auxiliary landing gear energy absorption in addition to airframe crushing and seat energy absorption.

21. Moseley, Harry, Colonel, et al, RELATION OF INJURY TO FORCES AND DIRECTION OF DECELERATION IN AIRCRAFT ACCIDENTS, Journal of Aviation Medicine, Vol. 29, October 1958.

The article reviews all major cargo-and transport-type aircraft accidents in the U. S. Air Force during a 2-year period to determine the path that such aircraft follow during actual crashes and to relate this to variations in aircraft attitude and to injury of occupants. The results indicate that the airframe tends to follow its established path and to remain stable around its own axis. At high velocities, the airframe continues in its established course even though major components are destroyed. With decreased velocity, major course and attitude deviations may result primarily from striking impeding objects. Most injuries are sustained when the aircraft is experiencing little deviation from its established path. The most obvious and most easily effected remedial measures would involve improvement of structural and retention strength of aircraft seats and moorings. These should be designed to provide maximum protection against fore and aft deceleration with additional consideration being given to designing for relatively small yaw deviation.

22. Brinkley, James W., DEVELOPMENT OF AEROSPACE ESCAPE SYSTEMS, Air University Review, July-August 1968.

This article reviews the development of aerospace escape systems from the aeromedical standpoint and describes recent advances that have made it possible to define more completely the human factors limiting the escape system performance envelope. The parameters which directly or indirectly determine if the ejectee will be injured by the ejection acceleration are the maximum acceleration, duration of maximum acceleration, and rate and duration of the entire acceleration. Within the last 5 to 10 years, there has been improvement in the methodology to describe human systems. The use of the Dynamic Response Index (DRI) to model the critical mode of injury when accelerations are applied parallel to the vertebrae is discussed.

23. Weinberg, L. W. T., CRASHWORTHINESS EVALUATION OF AN ENERGY ABSORPTION EXPERIMENTAL TROOP SEAT CONCEPT, Aviation Safety Engineering and Research; USATRECOM Technical Report 65-6, U. S. Army Transportation Research Command, Fort Eustis, Virginia, February 1965, AD614582.

This report describes an evaluation of an experimental troop seat concept that was progressively developed and dynamically tested. The seats were installed and tested along with other equipment in four full-scale crashes of CH-21 helicopters.

The designs represented progressive steps in the development of a troop seat using strut-type energy attenuation. The basic concept was a single-passenger, side-facing, bucket seat. Anthropomorphic dummies, restrained by lap belts and single diagonal chest straps, were placed in the seats to provide simulated human loading characteristics during impact. Accelerometers were mounted in the pelvic cavity of the dummies to permit recording of the impact decelerations. Floor accelerations were also measured near the seat installations. Tensiometers recorded the belt forces. High-speed cameras positioned in the helicopters recorded the reaction of the dummies and experimental seats during the crash sequences.

The seats were divided into two basic functional units: first, a seat base incorporating an energy-absorbing strut to provide the vertical support; and second, a curved nylon seat back that was designed to provide the occupant with restraint in the lateral and longitudinal directions, in addition to the restraint provided by the lap belt and chest strap. The test series demonstrated the effectiveness of strut-type energy absorption as a method of attenuating crash forces.

The report is presented such that each test involved is discussed as well as the overall analysis and evaluation. Photographs, acceleration records, and kinematic sketches are included where pertinent.

24. Bruggink, G. M., and Schneider, D. J., M.D., LIMITS OF SEAT BELT PROTECTION DURING CRASH DECELERATIONS, Aviation Crash Injury Research; TCREC 61-115, U. S. Army Transportation Research Command, Fort Eustis, Virginia, September 1961, AD 265868.

This report reviews three accidents in which aircraft occupants, restrained only by seat belts, received serious or fatal decelerative injuries. The study indicates some of the trauma that may be expected when the tolerable and injurious limits of seat-belt protection are exceeded.

The results indicate that full protection of seat-belt restraint can be realized only when the occupant has an unobstructed path for his flailing extremities and upper torso. If this condition does not exist, the protection offered by seat-belt restraint may not be limited by G factors but by the injurious aspects of the occupant's environment.

Seat-belt-caused injuries, in general, should not be considered as proof against a seat belt's usefulness, but as evidence of its necessarily limited protective value when compared to restraint systems that offer better load distribution over the entire skeleton.

To provide maximum protection, the strength of the occupant tie-down chain (seat, seat belt, floor) should be determined by the threshold between the injurious and fatal limits of seat-belt restraint.

An aircraft seat-belt restraint system with an energy-absorbing capability of 25 G's (occupant weight, 200 pounds) for a duration of at least 0.2 second may form a realistic compromise between the ideal and the practical dynamic strength of such a system.

25. Haley, J. L., HELICOPTER STRUCTURAL DESIGN FOR IMPACT SURVIVAL, U.S. Army Board of Aviation Accident Research, Ft. Rucker, Ala., November 1970.

This paper discusses the factors pertinent to crashworthiness design to enable occupants to survive the impact forces developed during a survivable crash. The paper presents results from a crash performance study of 71 utility helicopter accidents. In the paper it is concluded that:

- impact type injuries cause more fatalities than thermal injuries
- inadequate tie-down of transmission and rotor mast was the most severe structural weakness
- the most severe design weakness was the absence of suitable restraint harness or troop compartment doors to prevent ejection of occupants
- rollover and sideward type impact is a significant cause of occupant injury
- there is a lack of detailed specifications that has hindered crashworthiness design

The paper presents recommendations regarding crash environment, structural loads, and design concepts.

26. Smith, H. G., and McDermott, J. M., DESIGNING FOR CRASHWORTHINESS AND SURVIVABILITY, Hughes Tool Co., American Helicopter Society Proceedings, November 1968.

This paper discusses the prospects of intentionally designing for helicopter crashworthiness and survivability. Rotary-wing aircraft damage photographs are related to crash survivability design. The paper discusses the crash design survivability indices and human tolerance levels. Load factor versus deformation for equal crash energy absorption is compared, and the desirability of large deformation and correspondingly low load factors is explained. Several of the pertinent factors in designing for vertical impacts are presented. Present design practice is stated and future design objectives are presented.

27. Thompson, A. B., A PROPOSED NEW CONCEPT FOR ESTIMATING THE LIMIT OF HUMAN TOLERANCE TO IMPACT ACCELERATION, Aerospace Medical Journal, Vol. 33, No. 11, November 1962.

This article suggests that although mathematical techniques are being developed to determine human whole-body response to various impact accelerations, no satisfactory method is available for defining the human tolerance limit to impact loads resulting from abrupt accelerations. Limits set by total G vs. time, rate of onset, and velocity change are ill-defined and variable. A concept is proposed whereby limits are set by the force exerted per unit area on the body by the restraint or support system at maximum deceleration. Correlation is made between blast tolerance, sled test tolerance, and automobile accident and fall impact survivals, which indicates that 28 to 32 pounds per square inch is the onset level for shock and 45 to 55 pounds per square inch is the level for 50 percent mortality for transverse accelerations of less than 0.07 second duration. In this concept, G, rate of onset, and duration time are all dependent variables, while impact force per unit area, delta velocity change, and impact pulse time define the tolerance envelope.

28. MIL S-9749., A GENERAL SPECIFICATION FOR AIRCRAFT UPWARD EJECTION SEAT SYSTEM, Amended December 1969.

The following sections pertaining to crash loads are excerpted from the specifications:

"3.6.2.6 Crash loads

"3.6.2.6.1.1 Forward crash loads. The restraint subsystem and ejection seat installation shall be capable of withstanding the following loads.

"3.6.2.6.1.2 Seat installation. The ejection seat installation shall withstand a load of 40G ultimate applied in a forward direction through the seat structure to the seat attachment. The load shall be applied through the center of gravity of the seat/man combination, and the seat shall be in the most structurally critical position of adjustment during the load application. (One "G" equals 215 pounds plus the weight of the entire ejection seat system.)

"3.6.2.6.2 Side crash loads. The restraint subsystem and ejection seat installation shall withstand the loads specified in 3.6.2.6.1 applied in a direction of 20° to either side of the forward direction.

"3.6.2.6.3 Vertical crash loads. The restraint subsystem and ejection seat installation shall be capable of withstanding the following loads:

"a. Restraint subsystem - A load of 1,750 pounds ultimate applied to the restraint subsystem in a vertical upward direction and through the center of gravity of the occupant. The seat shall be in the most structurally critical position during the load application.

"b. Seat bucket - A load of 4,300 pounds ultimate applied downward perpendicular to the seat bucket bottom and through the center of gravity of the seat occupant. The load shall be distributed over the seat bucket bottom. The seat shall be adjusted to the upper limit of vertical adjustment during the load application.

"c. Seat installation - A load of 20G ultimate applied in a vertical downward direction perpendicular to and uniformly distributed over the seat bucket. (one G equals 215 pounds plus weight of the entire ejection seat system.)

"3.6.2.6.4 Back crash loads. The ejection seat shall be capable of withstanding a load of 1,500 pounds ultimate (1,000 pounds proof) distributed thereon below the headrest. The seat shall be adjusted to the most structurally critical vertical adjustment position for the application of this load."

29. MIL-T-27422B AIRCRAFT CRASH RESISTANT FUEL TANK MILITARY SPECIFICATION, Amended February 1970.

Paragraph 4.6.6.2 applies to crash impact design and reads as follows:

"The No. 2 test cube with cover plate attached to the fitting and filled with 770 pounds of water (no air in the cube) and held loosely with a sling made of webbing in accordance with Figure 9 shall be lifted to a height of 65 feet, measured from the bottom of the cube. With the bottom of the cube in a horizontal position, the release mechanism shall be actuated and the cube allowed to drop freely on a nondeforming surface. Any rupture resulting in spillage shall constitute failure."

30. MIL S-8698, HELICOPTER STRUCTURAL DESIGN REQUIREMENTS MILITARY SPECIFICATION, July 1954.

Paragraph 3.4.7 applies to design for crash loads and reads as follows:

"Sufficient strength shall be provided in the seat installation and attachments of engines, transmissions, equipment, and useful load items (including fuel tanks one-half full) and their carry-through structure to prevent failure of such attachments which would result in injury to personnel. The ultimate inertia-load factors shall be those specified by the procuring activity."

31. MIL S-58095, GENERAL MILITARY SPECIFICATION FOR AIRCREW NON EJECTION CRASHWORTHY SEAT SYSTEM, August 1971.

This specification describes a 95th percentile potentially survivable accident which specifies the time period, peak G values, and velocity change for a triangular pulse shape. The pulse parameters are obtained from USAAVLABS Technical Report 70-22. The specifications consider designing for human tolerance to vertical accelerations. The specification describes the seat system requirements necessary to provide occupant protection and survival in aircraft accidents.

Longitudinal, lateral, and upward seat structural strength and deformation requirements stated are based on the 95th percentile clothes occupant weight plus the weight of the seat and any equipment attached to or carried by the seat. Downward seat structural strength and deformation requirements are based on the effective weight of the 50th percentile clothed occupant plus the weight of that portion of the seat which must stroke during vertical crash force attenuation.

32. Haley, J., PRELIMINARY DRAFT, COST EFFECTIVENESS OF CRASHWORTHY STRUCTURAL FEATURES IN A 9-13 PLACE HELICOPTER, USAAAVS, TN 72-1, U.S. Army Agency for Aviation Safety, Ft. Rucker, Ala.

This report discusses the results of a cost-effectiveness study of crashworthy structural features for a 9-13 place helicopter. The study takes into consideration the following:

- accident history of the UH-1
- cost to the government of personnel injuries and fatalities
- savings potential on aircraft damage repair and replacement costs
- increased operating costs as a result of increased empty weight

The preliminary draft concludes that the crashworthy features intended for the UTTAS will be cost effective in 5.4 years on the basis of (1) an estimated initial cost increase of $15,000 per aircraft and (2) an accident rate equal to half that of the UH-1 series in FY 69.

TABLE I. LITERATURE SURVEY SUBJECT INDEX

REPORT NO. REF	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Rotary Wing Aircraft	●	●	●							●		●	●	●	●	●	●	●	●	●			●		●	●	●		●	●	●	●
Fixed Wing Aircraft	●	●		●	●	●	●	●	●			●	●	●	●	●			●		●	●		●			●	●	●		●	
Design Principles	●	●		●				●																	●	●					●	
Structural Design Criteria				●																					●	●					●	
MIL Specification Requirements		●											●															●	●	●	●	
Crash Environment	●	●	●		●	●	●			●											●		●			●			●	●	●	
Aircraft Loads and Accelerations	●	●	●		●	●	●		●	●											●											
Structural Behavior	●	●		●				●												●												
Airframe Struct. & Matls.	●			●									●																			
Energy Absorption	●	●		●				●								●			●	●			●									
Restraint Systems		●		●									●	●	●				●				●	●				●			●	
Seat and Harness Design		●		●									●	●	●				●				●					●			●	
Postcrash Design Criteria		●		●																												
Ancillary Equipment		●	●																													
Analytical Methods			●					●	●																							
Test Methods					●	●	●	●		●				●									●	●					●		●	
Test Data	●		●		●	●	●	●		●						●							●	●								
Analytical/Test Correlation			●																			●										
Accident Data		●	●				●										●	●		●	●			●	●							●
Failure Modes and Sequence			●	●				●		●										●												
Failure Analysis	●				●	●																										
Human Tolerance Levels		●	●				●			●	●	●	●	●	●				●	●		●					●				●	
Injury Data											●				●			●			●			●	●		●					
Dynamic Response							●	●			●	●		●		●						●					●	●			●	
Structural Systems					●	●	●		●							●												●	●	●	●	
Human Systems											●	●		●	●							●										
Escape Systems		●	●										●									●						●				
Cost Effectiveness																																●

DESCRIPTION OF STAGS(STRUCTURAL ANALYSIS OF GENERAL SHELLS)PROGRAM

STAGS is a computer program developed to analyze the behavior of general shells under arbitrary static thermal and mechanical loading. Nonlinearities caused by material behavior and finite deformations are accounted for. The STAGS analysis is based on an energy formulation. Derivatives which appear in the energy expression are replaced by their two-dimensional finite difference approximations. Minimization of the energy results in a system of nonlinear algebraic equations which are solved by use of a modified Newton-Raphson method.

The computer program STAGS (Structural Analysis of General Shells) performs a nonlinear analysis of shells by use of a two-dimensional finite difference approach. Displacement and stress histories are computed corresponding to a given history of applied load, displacement, or temperature. Two versions of STAGS are described in this report. The first version provides an elastic nonlinear collapse analysis. In addition to the basic nonlinear branch, there are two special branches: the first is for linear analysis, and the second is for buckling analysis based on the classical bifurcation approach with a linear prebuckling analysis. Collapse loads are found as limit points in the nonlinear load displacement curve. The program is useful for postbuckling analysis of shells which behave according to classical buckling theory and for studies of the influence of imperfections.

STAGS applies to any shell for which a reference surface and a suitable set of grid lines can be mathematically defined. In general, the user of the program provides a subroutine describing the geometry, but several such routines for standard geometries are permanently included in the program. For the elastic version, the shell wall thickness can be varied, and elastic properties are allowed to vary with the shell coordinates and through the thickness. Cutouts in the shell wall and discrete eccentric stiffeners are included. The program is also general relative to boundary conditions and to loading. The loading can be applied in terms of variable surface tractions, point forces, or line loads. Displacements, such as uniform end shortening of a cylindrical shell, can be applied if desired rather than fixed loading, and provision is made for thermal loading.

Stiffeners and cutout edges must follow coordinate lines, or rather the coordinate lines must be chosen so that they follow boundaries, internal or external, and the direction of internal stiffeners. This is not a severe program limitation because the capability of handling nonorthogonal grids has been included. However, analysis of more complicated shells will require some user skill.

On each of the boundaries, the input parameters can be used to specify restraint on either of the three displacement components or on the rotation about the tangent to the edge. If displacement restraint is not specified for one or more of these qualities, the analysis will be based on appropriate natural boundary conditions (stress free). If more complicated boundary conditions are used, it will be necessary to modify the program in an area which is not easily accessible to the user. However, displacement restraints off the boundary lines can be introduced by using specified displacement in the load routine.

Two items are of special importance relative to the problem of computer run time. One is the transformation of the structure into a model which is suitable for analysis; the other is the choice of strategy in the nonlinear analysis. Often, it is impossible to model the structure in a straightforward manner, and considerable engineering skill may be needed. Eventually a few different models must be analyzed, all reflecting different types of local behavior. The strategy in the analysis involves choice of such items as step size and convergence criterion; it also involves the use of initial imperfections and the use of the results from the application of the bifurcation analysis. The choice of a proper strategy is very important for computer economy.

The basic problem dimensions (number of nodal points in each direction) are restricted only by the availability of mass storage. Some program limitations are imposed by dimension statements. In each direction, there can be as many as 80 stiffeners but only of 20 different types. The number of points for integration through the thickness must be an odd number, and it may not exceed 9. In the plasticity analysis, as many as 10 material components may be used.

A comprehensive description of STAGS can be found in Reference 42.

MATHEMATICAL MODEL DESCRIPTION

PROGRAM KRASH

Program KRASH was developed during Phase II of the study described herein. Program KRASH computes the time history response of N arbitrarily interconnected lumped masses. Each mass is allowed six degrees of freedom defined by inertial coordinates x_i, y_i, z_i and Eulerian angles ϕ_i, θ_i, ψ_i, $i = 1,2,\ldots N$. Euler's equations of motion are written for each mass. The equations of motion are integrated numerically to obtain velocities and displacements and rotations. Angular momentum terms due to rotor angular velocity are included in the equations of motion.

The following loads (forces and moments) act on each lumped mass:

1. Gravity forces
2. Aerodynamic forces
3. Internal forces and moments
4. External forces and moments

The gravity forces are self-explanatory. The aerodynamic forces consist of the simple lift force on each mass held constant throughout the run. This lift force is computed for each mass as an input fraction of the total vehicle weight.

The internal forces and moments result from the deformation of structural members, termed "beams", which interconnect the various lumped masses. The degree of interconnectivity, i.e., which of the N masses are interconnected, is specified in the input. Each beam's properties are specified in terms of a 6 x 6 linear stiffness matrix relating the forces and moments at mass j to the relative deflections and rotations of mass j with respect to mass i.

The actual internal forces are computed on an incremental basis. Each increment is just the incremental linear force determined from the stiffness matrix, times the incremental deflection, multiplied by a stiffness reduction factor KR. For each beam element there are six different KR's, one for each relative deflection. For a given relative deflection, say, axial deflection, the corresponding KR applies to all six possible loads due to this deflection. Each KR is input as a tabular function of the corresponding deflection. For small deflections, KR = 1, so that a linear analysis is obtained; for larger deflections, KR $\neq$ 1, so that general plastic deformations are allowed. Since the forces are computed incrementally, KR is simply the slope of the appropriate load-stroke curve.

The structural element is assumed to behave the same under the influence of positive and negative loads.

In addition to the above, the internal load computation is written such that unloading and subsequent reloading occur along a linear elastic line. Once any of the six deflections exceeds an input value, the member is assumed to have failed completely (fracture) and the interconnecting forces are set to zero for the remainder of the run. Linear (viscous) damping is included in the calculation of the internal loads.

The external forces result from the crushing of structure which is external to the lumped masses. Each lumped mass is allowed to have as many as three mutually perpendicular "springs" which radiate outward from the mass. Obviously, only those masses on the exterior of the vehicle will utilize these springs. When any spring contacts the ground, an axial spring compression load is calculated from an input table of spring axial load versus axial compression.

This table can be input in any form to allow for general elastic-plastic deformation. Unloading (extending) and reloading follow an elastic line whose stiffness is input, so that energy is absorbed in permanent deformation. In addition, beyond an input maximum deflection, further loading-unloading proceeds along a steep elastic line (input constant). This is to represent the finite crushing distance available, beyond which the stiffness increases drastically. The external springs do not develop tensile loads, and they do not fracture as do the internal "beams".

A ground drag load is computed at the ground contact point for each spring. This load is just a constant input friction coefficient times the normal component of the axial spring load. The direction of the drag load is opposite to the velocity vector of the contact point. The contact surface (ground) is assumed to be flat and rigid.

Program KRASH has a built-in routine which will determine when an identified mass penetrates a defined occupiable volume. In addition, the program will obtain the Dynamic Response Index (DRI) for desired personnel locations. Program KRASH uses a modified predictor-corrector integration routine and includes an initial condition subroutine which provides for a balanced vehicle at the start of the analysis.

THEORY

Mathematical Model of Helicopter

The helicopter is modeled as a series of interconnected lumped masses. Each mass is allowed six degrees of freedom, three translations, and three rotations. The masses are connected internally by nonlinear beam elements. Each mass is allowed up to three external nonlinear "springs", which radiate outward from the mass and contact the ground, providing external crash forces. The helicopter model is shown in Figure 1.

m_i, m_j and m_k are three lumped masses, interconnected by beams ij and ik. Three external springs are shown radiating outward from m_k. The end points of these springs are denoted by C_{xk}, C_{yk} and C_{zk}. The center-of-gravity of the entire helicopter is denoted by G. (In general, there will be no lumped mass exactly at G.)

Coordinate Systems

Definition of Coordinate Systems

1. Ground Coordinate System $(O_{,x,y,z})$. This is a right-handed coordinate system fixed in the ground with origin at point O in Figure 1. The x axis is positive forward, the y axis positive to the right, and the z axis positive downward. The xy plane (z = 0) corresponds to the ground surface. The ground coordinate system is considered an inertial coordinate system for writing the dynamic equations of motion.

2. Helicopter Coordinate System $(H_{,x'',y'',z''})$. This is a left-handed coordinate system fixed in the helicopter with origin at point H in Figure 1. The x" axis is positive aft, y" is positive left, and z" is positive upward. The origin, point H, corresponds to F.S.O., B.L.O, W.L.O. This coordinate system is used only to input the coordinates of the lumped mass points, since the coordinates of the points are usually available in terms of F.S., B.L. and W.L.

3. Center-of-Gravity Coordinate System $(G_{,x',y',z'})$. This is a right-handed system fixed in the helicopter with the origin at the c.g. of the helicopter (Point G). The x' axis is positive forward, y' positive right, and z' positive downward. These axes are parallel to the $H_{x'',y'',z''}$ axes.

4. Body Coordinate System (m_i, x_i, y_i, z_i). Each lumped mass has its right-handed coordinate system fixed in the mass. The orientation of each of these coordinate systems is arbitrary, and it is specified by means of three input Euler angles for each mass, relating its orientation to the $G_{x'y'z'}$ center-of-gravity coordinate system.

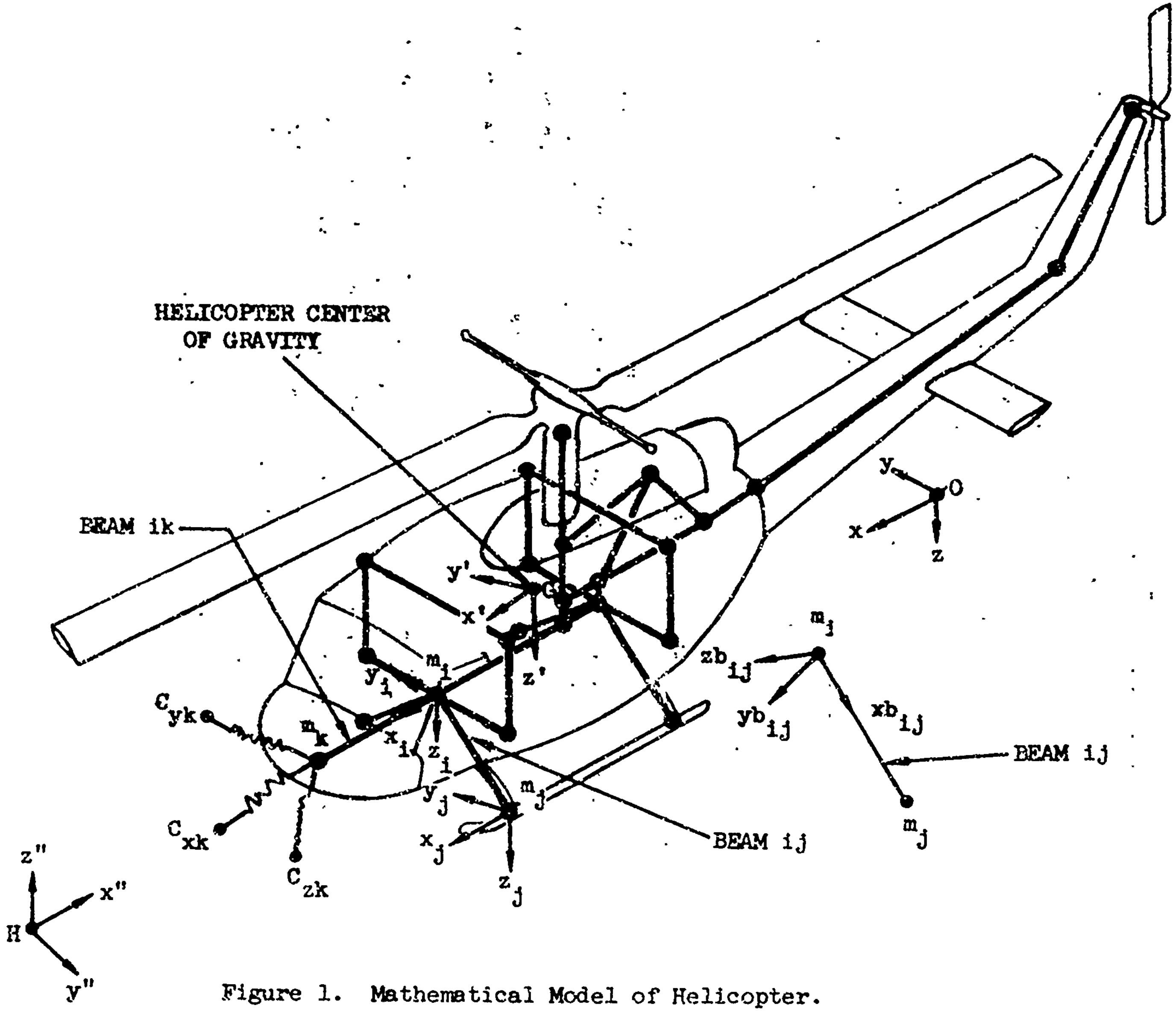

HELICOPTER CENTER OF GRAVITY
BEAM ik
y
O
x
z
y'
x'
z'
G
m_i
y_i
x_i
z_i
m_k
C_{yk}
C_{xk}
C_{zk}
y_j
m_j
x_j
z_j
BEAM ij
m_i
zb_{ij}
yb_{ij}
xb_{ij}
BEAM ij
m_j
z"
x"
H
y"

Figure 1. Mathematical Model of Helicopter.

Normally the body coordinate system is taken parallel to the center-of-gravity coordinate system (and hence, the three input Euler angles are set = 0), since the inertia data is generally available about these axes. The body coordinate system is the system used in writing Euler's equations of motion for each lumped mass m_i.

5. Beam Coordinate System ($m_i, xb_{ij}, yb_{ij}, zb_{ij}$). This is a right-handed coordinate system fixed in mass m_i, with its origin at m_i. The xb_{ij} is along a straight line from m_i to m_j, with the helicopter in its original undeformed configuration. As the helicopter deforms, this coordinate system remains fixed in mass m_i, so that xb_{ij} will no longer point to m_j. The direction of yb_{ij} and zb_{ij} (they are mutually perpendicular) is arbitrary and is input to the program. Each beam ij has a beam coordinate system, used to compute the beam forces and moments.

Relations Between Coordinate Systems

Any quantity which can be expressed as a vector in one coordinate system (forces, moments, displacements, velocities, accelerations, but not large rotations) can be, likewise, specified in another coordinate system by use of an Eulerian transformation matrix relating the two coordinate systems. Thus, for example, if we have a force vector at m_i expressed in its body axes components as (X_i, Y_i, Z_i), this can be expressed in ground axes as simply

$$\begin{Bmatrix} X_{oi} \\ Y_{oi} \\ Z_{oi} \end{Bmatrix} = \begin{bmatrix} A_i \end{bmatrix} \begin{Bmatrix} X_i \\ Y_i \\ Z_i \end{Bmatrix}$$

where $\{X_{oi}, Y_{oi}, Z_{oi}\}$ are the ground axes components of the force vector and $|A_i|$ is a 3 x 3 Eulerian transformation matrix. The form of $|A_i|$ depends on the sequence in which rotations from one axis system to the other are performed. In this program, the following sequence is employed:

1. Starting with the O, x, y, z coordinate system, perform a clockwise (right-hand rule) rotation about the O_z axis, through an angle ψ_i.

2. Next, perform a clockwise rotation about the new O_y axis, through an angle θ_i.

3. Finally, perform a clockwise rotation about the final O_x axis, through an angle ϕ_i.

The resulting transformation matrix is then inverted to obtain a transformation from body axes to ground axes. The resulting transformation matrix is given by

$$A_i = \left[\begin{array}{c|c|c} \mathrm{COS}\theta_i\ \mathrm{COS}\psi_i & -\mathrm{COS}\phi_i\ \mathrm{SIN}\psi_i + \mathrm{SIN}\phi_i\ \mathrm{SIN}\theta_i\ \mathrm{COS}\psi_i & \mathrm{SIN}\phi_i \mathrm{SIN}\psi_i + \mathrm{COS}\phi_i \mathrm{SIN}\theta_i \mathrm{COS}\psi_i \\ \mathrm{COS}\theta_i\ \mathrm{SIN}\psi_i & \mathrm{COS}\phi_i\ \mathrm{COS}\psi_i + \mathrm{SIN}\phi_i\ \mathrm{SIN}\theta_i\ \mathrm{SIN}\psi_i & -\mathrm{SIN}\phi_i \mathrm{COS}\psi_i + \mathrm{COS}\phi_i \mathrm{SIN}\theta_i \mathrm{SIN}\psi_i \\ -\mathrm{SIN}\theta_i & \mathrm{SIN}\phi_i\ \mathrm{COS}\theta_i & \mathrm{COS}\phi_i\ \mathrm{COS}\theta_i \end{array}\right] \tag{1}$$

Similar transformation matrices are formed to relate various other coordinate systems. These are summarized in Table II.

TABLE II. TRANSFORMATION MATRICES

Matrix	Transforms From	To	Using Angles	Angles Constant or Varying
$[A_i]$	ith body axes	ground axes	ϕ_i, θ_i, ψ_i	varying
$[A_{ij}]$	beam ij axes	ith body axes	ϕ_{ij}, θ_{ij}, ψ_{ij}	constant
$[A_i'']$	ith body axes	c.g. axes	ϕ_i'', θ_i'', ψ_i''	constant
$[A']$	c.g. axes	ground axes	ϕ', θ', ψ'	constant

All the above matrices utilize equation (1) with the appropriate angles from the above table. $[A_i'']$ and $[A']$ are used only in initial conditions determination, so that their Euler angles are indicated as constant.

These "constants" are really the time zero values of the angles which actually vary but are not used in the time history computations. ϕ', θ', ψ' are input constants defining the initial attitude of the overall vehicle. The $\left[A_{ij}\right]$ matrices are constant since, as mentioned above, the ij beam axes are fixed in the ith body axes. Hence, the only time varying Euler angles are ϕ_i, θ_i, and ψ_i in the $\left[A_i\right]$ matrices. These obviously are the three rotational degrees-of-freedom of the ith lumped mass.

We also will require the time derivative of the $\left[A_i\right]$ matrix, denoted $\left[\dot{A}_i\right]$ It can be shown that this is given by postmultiplying $\left[A_i\right]$ by a matrix $\left[D_i\right]$ so that

$$\left[\dot{A}_i\right] = \left[A_i\right] \left[D_i\right] \qquad (2)$$

where $\left[D_i\right]$ is given by

$$\left[D_i\right] = \left[\begin{array}{c|c|c} 0 & \dot{\theta}_i \sin\phi_i - \dot{\psi}_i \cos\phi_i \cos\theta_i & \dot{\theta}_i \cos\phi_i + \dot{\psi}_i \sin\phi_i \cos\theta_i \\ -\dot{\theta}_i \sin\phi_i + \dot{\psi}_i \cos\phi_i \cos\theta_i & 0 & -\dot{\phi}_i + \dot{\psi}_i \sin\theta_i \\ -\dot{\theta}_i \cos\phi_i - \dot{\psi}_i \sin\phi_i \cos\theta_i & \dot{\phi}_i - \dot{\psi}_i \sin\theta_i & 0 \end{array}\right] \qquad (3)$$

Sign Conventions

The basic sign convention used for all displacements, rotations, velocities, accelerations, forces and moments is that all quantities are positive in the positive direction of the axes shown in Figure 1. Rotation and moments utilize a right-hand rule to define the positive direction. The few exceptions to this rule are indicated in the theoretical development.

Forces Acting on Each Mass

The following forces and moments act on each lumped mass:

1. Gravity forces
2. Aerodynamic forces
3. Internal forces and moments
4. External forces and moments

5. Damping forces and moments (internal)

All forces and moments are positive when they act in the positive direction of the m_i, x_i, y_i, z_i axes.

Gravity Forces (X_{G_i}, Y_{G_i}, and Z_{G_i})

The gravity force for the ith lumped mass is evidently just the weight W_i acting along the ground fixed O_z axis. Transforming this force into body axes gives the gravity forces as

$$\left\{ \begin{array}{c} X_{G_i} \\ Y_{G_i} \\ Z_{G_i} \end{array} \right\} = \left[A_i\right]^T \left\{ \begin{array}{c} 0 \\ 0 \\ W_i \end{array} \right\} \qquad (4)$$

where $\left[A_i\right]^T$ indicates the transpose of $\left[A_i\right]$. Note that the transpose rather than the inverse is used, since for rotation transformation matrices the two are equal.

Aerodynamic Forces (X_{A_i}, Y_{A_i}, and Z_{A_i})

The only aerodynamic forces considered are a constant lift force, in ground axes, positive upward, acting on each lumped mass. This lift force is expressed as a constant fraction of the total vehicle weight, times the vehicle weight:

$$\text{LIFT}_i = l_{c_i} W_{TOT} \qquad (5)$$

where

$$W_{TOT} = \sum_{i=1}^{N} W_i \qquad (6)$$

and N is the total number of lumped masses. Transforming this lift into ith body axes gives the desired aerodynamic forces as

$$\begin{Bmatrix} X_{A_i} \\ Y_{A_i} \\ Z_{A_i} \end{Bmatrix} = \left[A_i\right]^T \begin{Bmatrix} 0 \\ 0 \\ -\mathrm{LIFT}_i \end{Bmatrix} \tag{7}$$

where the minus sign is necessary because the lift is positive upward (in the negative direction of the O_z ground axis.)

Inputting all $lc_i = 0$ gives a zero lift case, generally the most common. If a 100% lift case is desired, and it is assumed that all the lift is from the rotor, then input $lc_i = 1$ for the ith mass corresponding to the rotor.

Internal Forces and Moments (X_{I_i}, Y_{I_i}, Z_{I_i}, M_{I_i}, and N_{I_i})

These forces and moments result from the deformations of the interconnecting beams as the lumped masses move. First, for beam ij, the deflections and rotations of point j with respect to point i are computed in beam ij axes. These are then used to calculate the three forces and three moments at point j, utilizing a 6 x 6 stiffness matrix relating the loads to the deformations. Nonlinear effects are also included in computing the loads. The loads at point j in beam axes are then transformed into ground axes, and the loads at point i in ground axes are computed from static equilibrium equations (the beams are assumed massless). Then the loads at i and j are transformed into ith and jth mass body axes, respectively. Finally, for each mass the contributions from the various beams that attach to that mass are summed to obtain the total internal force for the mass. All the internal force calculations are performed on an incremental basis, i.e., incremental deflections are used to compute incremental forces, since a tangent modulus is utilized for computing nonlinear effects.

1. Beam Deformations - This section calculates the deflections and rotations of point j with respect to point i, for beam ij, in beam ij axes. First, the incremental deflections of point j with respect to point i, in ground axes, are clearly given by

$$\begin{Bmatrix} \Delta x_{ij} \\ \Delta y_{ij} \\ \Delta z_{ij} \end{Bmatrix} = \begin{Bmatrix} \Delta x_j \\ \Delta y_j \\ \Delta z_j \end{Bmatrix} - \begin{Bmatrix} \Delta x_i \\ \Delta y_i \\ \Delta z_i \end{Bmatrix} \qquad (8)$$

Δx_i and Δx_j are the incremental displacements of points i and j, from one time interval to the next, obtained by numerical integration of the velocities. The running time sums of these quantities give the total coordinate positions, x_i , y_i , z_i :

$$\begin{aligned} x_i &= x_i + \Delta x_i \qquad i = 1, 2, \ldots, N \qquad (9) \\ y_i &= y_i + \Delta y_i \\ \underset{\text{current value}}{z_i} &= \underset{\text{previous value}}{z_i} + \Delta z_i \end{aligned}$$

x_i, y_i, z_i are the three translational degrees of freedom of mass i. Referring to Figure 1, they give the position of the ith mass in the ground $(0_{x,y,z})$ coordinate system. Similarly, the three Euler angles ϕ_i, θ_i, ψ_i mentioned earlier are the three rotational degrees of freedom of mass i. Since incremental values of these are also used, we have

$$\begin{aligned} \phi_i &= \phi_i + \Delta\phi_i \\ \theta_i &= \theta_i + \Delta\theta_i \qquad i = 1,2,\ldots,N \qquad (10) \\ \underset{\text{current value}}{\psi_i} &= \underset{\text{previous value}}{\psi_i} + \Delta\psi_i \end{aligned}$$

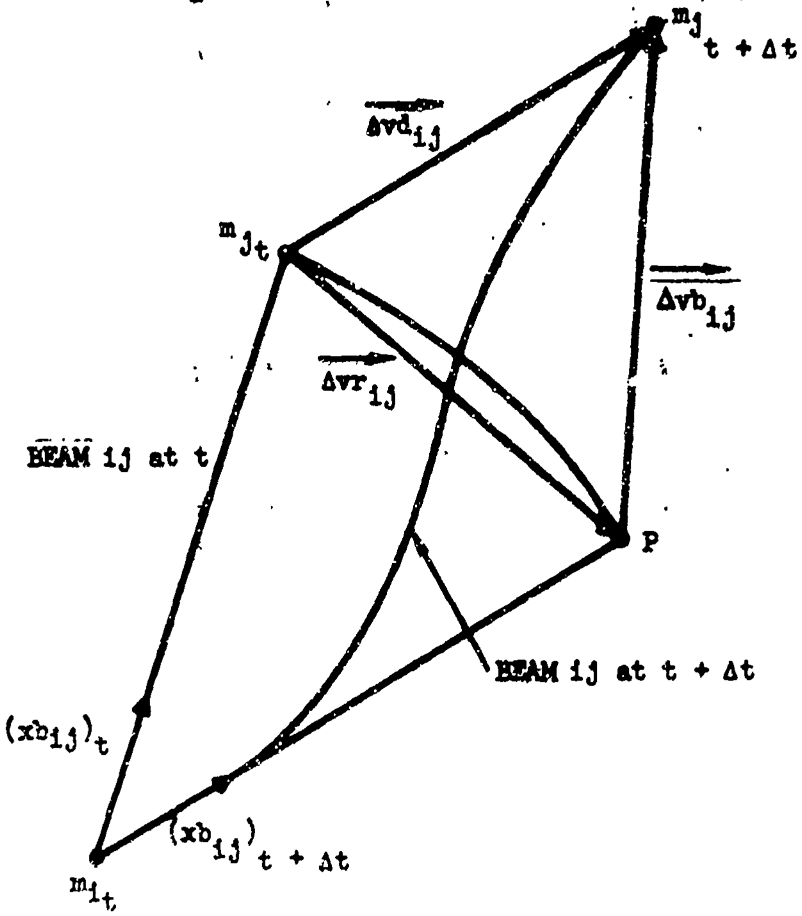
Figure 2 illustrates beam ij in two positions, at time t and time t + Δt, where Δt is the numerical integration time interval. Mass i is shown as not moving during Δt, which is done only to clarify the figure. Mass j moves from m_{jt} to $m_{jt+\Delta t}$ during the Δt time interval. This motion can be viewed as resulting from two vector motions.

$$\overrightarrow{\Delta vd}_{ij} = \overrightarrow{\Delta vr}_{ij} + \overrightarrow{\Delta vb}_{ij} \tag{11}$$

$\overrightarrow{\Delta vd}_{ij}$ is clearly given by equation (8) in ground axes, i.e.,

$$\overrightarrow{\Delta vd}_{ij} = \begin{Bmatrix} \Delta x_{ij} \\ \Delta y_{ij} \\ \Delta z_{ij} \end{Bmatrix} \tag{12}$$

The first component of $\overrightarrow{\Delta vd}_{ij}$, Δvr_{ij} is the deflection of point j due solely to rotation of mass m_i during Δt. In Figure 2, the coordinate axis (xb_{ij}) is shown rotating clockwise to its new position, due to rotation of mass m_i (recall that the beam axes are fixed in mass i).



$m_{j_{t+\Delta t}}$
$\overrightarrow{\Delta vd_{ij}}$
m_{j_t}
$\overrightarrow{\Delta vb_{ij}}$
$\overrightarrow{\Delta vr_{ij}}$
BEAM ij at t
P
BEAM ij at t + Δt
$(xb_{ij})_t$
$(xb_{ij})_{t+\Delta t}$
m_{i_t}

Figure 2. Beam Deflections.

This motion alone moves point m_{jt} over to point P in Figure 2.

However, this motion alone would induce no loading in beam ij. The fact that point j actually moves to $m_{jt+\Delta t}$ causes the beam loads. Thus, it is clearly the vector $\overrightarrow{\Delta vb}_{ij}$ that gives the incremental beam deformations that cause incremental beam loads. Solving equation (11) for the desired deflections $\overrightarrow{\Delta vb}_{ij}$:

$$\overrightarrow{\Delta vb}_{ij} = \overrightarrow{\Delta vd}_{ij} - \overrightarrow{\Delta vr}_{ij} \qquad (13)$$

$\overrightarrow{\Delta vd}_{ij}$ is already known, in ground axes, from equation (12).

$\overrightarrow{\Delta vr}_{ij}$ is now determined. At time t, a vector from i to j in ground axes, defined as $\{x_{ij}, y_{ij}, z_{ij}\}$, is given by

$$\begin{Bmatrix} x_{ij} \\ y_{ij} \\ z_{ij} \end{Bmatrix} = \begin{Bmatrix} x_j - x_i \\ y_j - y_i \\ z_j - z_i \end{Bmatrix} \qquad (14)$$

This vector in ith body axes (denoted ') is just

$$\begin{Bmatrix} x'_{ij} \\ y'_{ij} \\ z'_{ij} \end{Bmatrix}_t = \left[A_i\right]_t^T \begin{Bmatrix} x_{ij} \\ y_{ij} \\ z_{ij} \end{Bmatrix}_t \qquad (15)$$

where the subscript t denotes at time t. This same vector at time t + Δt, where mass i has now rotated but the vector remains unchanged in inertial space, is given by

$$\begin{Bmatrix} x'_{ij} \\ y'_{ij} \\ z'_{ij} \end{Bmatrix}_{t+\Delta t} = \left[A_i\right]^T_{t+\Delta t} \begin{Bmatrix} x_{ij} \\ y_{ij} \\ z_{ij} \end{Bmatrix}_t \tag{16}$$

where $\left[A_i\right]^T_{t+\Delta t}$ is now evaluated with the new rotated angles.

The desired $\overrightarrow{\Delta vr}_{ij}$ is evidently just (15) minus (16),

$$\overrightarrow{\Delta vr}_{ij} = \left\{\left[A_i\right]^T_t - \left[A_i\right]^T_{t+\Delta t}\right\} \begin{Bmatrix} x_{ij} \\ y_{ij} \\ z_{ij} \end{Bmatrix}_t \tag{17}$$

Substituting "previous" for values at t, and not denoting the values at t + Δt (since the new $\left[A_i\right]$ is evaluated before these calculations), we have

$$\overrightarrow{\Delta vr}_{ij} = \left\{\left[A_i\right]^T_{prev.} - \left[A_i\right]^T\right\} \begin{Bmatrix} x_{ij} \\ y_{ij} \\ z_{ij} \end{Bmatrix}_{prev.} \tag{18}$$

in current ith mass axes. Rotating into beam ij axes, we obtain

$$\overrightarrow{\Delta vr}_{ij} = \left[A_{ij}\right]^T \left\{\left[A_i\right]^T_{prev.} - \left[A_i\right]^T\right\} \begin{Bmatrix} x_{ij} \\ y_{ij} \\ z_{ij} \end{Bmatrix}_{prev.} \tag{19}$$

Returning to equation (13), we still require $\overrightarrow{\Delta vd}_{ij}$, in beam ij axes. This is evidently given by

$$\overrightarrow{\Delta vd}_{ij} = \left[A_{ij}\right]^T \left[A_i\right]^T \begin{Bmatrix} \Delta x_{ij} \\ \Delta y_{ij} \\ \Delta z_{ij} \end{Bmatrix} \tag{20}$$

Finally, combining (19) and (20) into (13), we obtain the desired $\overrightarrow{\Delta vb}_{ij}$ in beam ij axes:

$$\overrightarrow{\Delta vb}_{ij} = \begin{Bmatrix} \Delta xb_{ij} \\ \Delta yb_{ij} \\ \Delta zb_{ij} \end{Bmatrix} = \left[A_{ij}\right]^T \left[\left[A_i\right]^T \begin{Bmatrix} \Delta x_{ij} \\ \Delta y_{ij} \\ \Delta z_{ij} \end{Bmatrix} - \left(\left[A_i\right]^T_{\text{prev.}} - \left[A_i\right]^T \right) \begin{Bmatrix} x_{ij} \\ y_{ij} \\ z_{ij} \end{Bmatrix}_{\text{prev.}} \right] \tag{21}$$

Equation (21) gives the three incremental beam deflections (point j relative to point i); the incremental rotations are now derived. The incremental rotations of point j relative to point i, in ith mass axes, are evidently given by

$$\begin{Bmatrix} \Delta\phi b_{ij} \\ \Delta\theta b_{ij} \\ \Delta\psi b_{ij} \end{Bmatrix}_{i \text{ axes}} = \left[A_i\right]^T \left[A_j\right] \begin{Bmatrix} \Delta inp_j \\ \Delta inq_j \\ \Delta inr_j \end{Bmatrix} - \begin{Bmatrix} \Delta inp_i \\ \Delta inq_i \\ \Delta inr_i \end{Bmatrix} \tag{22}$$

where the incremental angles on the right-hand side of the equation are the incremental changes in the integral of the angular velocities for masses i and j.

This equation assumes that the incremental rotations can be treated as vectors, which is true only for small angles. However, since Δt for the numerical integration is normally chosen quite small, these angles are sufficiently small to treat as vectors. Transforming (22) into beam ij axes, we obtain

$$\begin{Bmatrix} \Delta\phi b_{ij} \\ \Delta\theta b_{ij} \\ \Delta\psi b_{ij} \end{Bmatrix} = \left[A_{ij}\right]^T \left[\left[A_i\right]^T \left[A_j\right] \begin{Bmatrix} \Delta inp_j \\ \Delta inq_j \\ \Delta inr_j \end{Bmatrix} - \begin{Bmatrix} \Delta inp_i \\ \Delta inq_i \\ \Delta inr_i \end{Bmatrix} \right] \tag{23}$$

Equations (21) and (23) give us the three deflections and three rotations of point j with respect to point i, in beam ij axes. These are now utilized to compute the forces and moments at point j due to these deflections and rotations.

2. **Beam Forces and Moments at Point j** - The forces and moments at point j, in beam ij axes, denoted ΔF_{ijk} $(k = x,y,z,\phi,\theta,\psi)$, are indicated in Figure 3. These are the loads acting on the beam; the loads acting on mass j are equal in magnitude and opposite in direction. Positive loads acting on the beam at point j are in the same direction as the six relative deflections (j with respect to i) calculated in the previous section.

The incremental loads at j are calculated from the incremental deflections utilizing a 6 x 6 stiffness matrix for beam ij. This linear relationship is then modified by a diagonal stiffness reduction (KR_{ij}) matrix, resulting in the following governing equation for the incremental loads at point j:

$$\left\{\Delta F_{ij}\right\} = \left[K_{ij}\right]\left[KR_{ij}\right]\left\{\Delta vb_{ij}\right\} \tag{24}$$

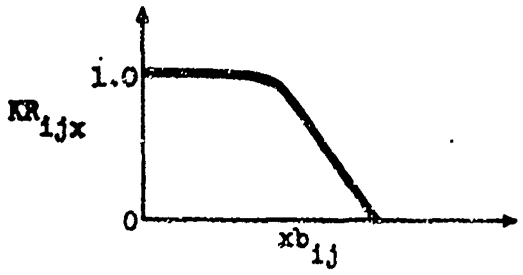
where $\left\{\Delta vb_{ij}\right\}$ is now defined as a six-element vector as follows:

$$\left\{\Delta vb_{ij}\right\} = \begin{Bmatrix} \Delta xb_{ij} \\ \Delta yb_{ij} \\ \Delta zb_{ij} \\ \Delta\phi b_{ij} \\ \Delta\theta b_{ij} \\ \Delta\psi b_{ij} \end{Bmatrix} \tag{25}$$

The elements of $\left\{\Delta vb_{ij}\right\}$ come from equations (21) and (23) from the previous section. Each element of $[KR_{ij}]$ is input to the program as a tabular function of the corresponding element of $\left\{vb_{ij}\right\}$, where $\left\{vb_{ij}\right\}$ is just the total beam deflection given by

$$\underset{\text{current}}{\left\{vb_{ij}\right\}} = \underset{\text{previous}}{\left\{vb_{ij}\right\}} + \left\{\Delta vb_{ij}\right\} \tag{26}$$

A typical KR_{ij} input table is shown in the following sketch:



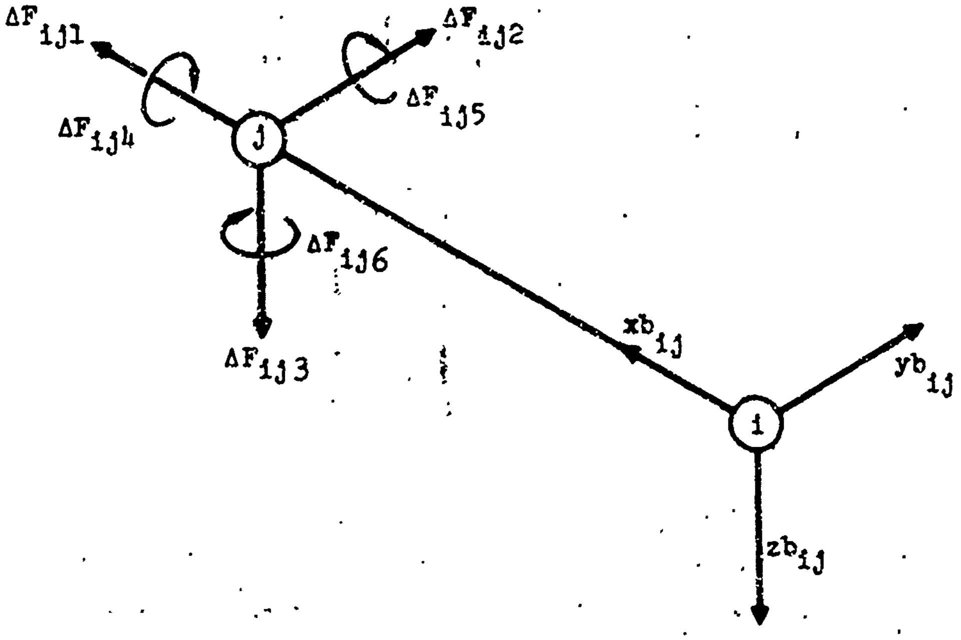
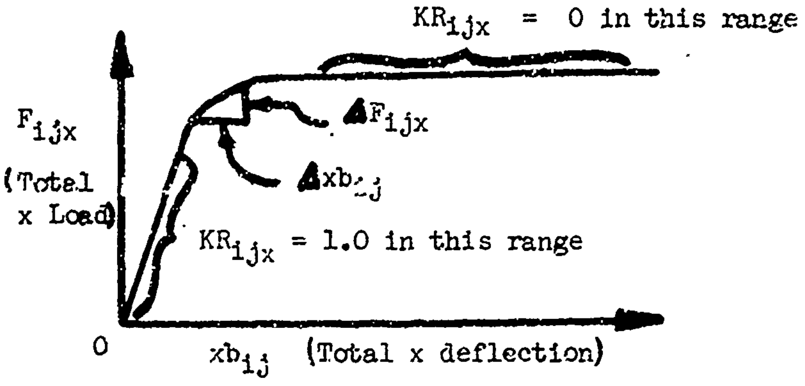

ΔF_{ij1}
ΔF_{ij2}
ΔF_{ij3}
ΔF_{ij4}
ΔF_{ij5}
ΔF_{ij6}
j
i
xb_{ij}
yb_{ij}
zb_{ij}

Figure 3. Beam Loads.

KR_{ijx} starts out at 1.0 for small deflections xb_{ij}, corresponding to a linear analysis. Beyond a certain limiting deflection, KR_{ijx} becomes less than 1.0, representing nonlinear softening of beam ij in the axial (x) direction. Since equation (24) is written on an incremental basis, each increment varies according to KR_{ij} so that a total load versus total deflection curve would look like the following:



Obviously the total loads are just the time sums of the incremental loads in (24):

$$\underset{\text{current}}{\left\{F_{ij}\right\}} = \underset{\text{previous}}{\left\{F_{ij}\right\}} + \left\{\Delta F_{ij}\right\} \tag{27}$$

The above illustration shows the x load varying only with the x deflection. In general, equation (24) shows each of the 6 loads varying with all 6 deflections, via the 6 x 6 $\left[K_{ij}\right]$ linear stiffness matrix. Thus, in general, any load depends on all 6 deflections and also all 6 KR_{ij} input tables. In practice, the stiffness matrix $\left[K_{ij}\right]$ would seldom be fully populated.

In addition to the nonlinear load capability just described, the program also allows for unloading and subsequent reloading to proceed along an elastic line. This is illustrated in Figure 4. The ordinate FM_{ijkl} is the total (over time) kth load due to the lth deflection vb_{ijl}, for beam ij. Also shown is a typical incremental load ΔFM_{ijkl} due to the incremental deflection Δvb_{ijl}. The ΔFM_{ijkl} are the six individual terms that make up each ΔF_{ijk} in equation (24), i.e.,

$$\Delta F_{ijk} = \sum_{l=1}^{6} \Delta FM_{ijkl} \qquad (28)$$

Thus, for example, Figure 4 could represent the total (over time) y force due to ψ rotations plotted against ψ rotation, for beam ij.

Loading proceeds along the solid line O-F-A. Unloading then proceeds along dashed line A-B, parallel to the original linear loading line O-F. Subsequent reloading then proceeds along B-A, until point A is reached. At this point, further loading proceeds along A-C. At point C, fracture occurs and the load drops to zero.

Note that if unloading occurs along the original elastic portion of the curve (O-F), unloading will be along F-O. The intent of this loading-unloading model is to represent crushing structure with elastic rebound.

The important feature represented here is the energy absorbed by the structure in a loading-unloading-reloading cycle such as O-F-A-B-C. It is felt that under the large deformation crash conditions that this program is intended to investigate, this energy absorption is far more significant than the small structural damping generally present.

A flow diagram for the calculation of the loading-unloading forces is shown in Figure 5. The equation for ΔFM_{ijkl} is just each term of equation (24); the summation over l gives the ΔF_{ijk} of (24). In Figure 5, if $K_{ijkl} \neq 0$, then the sign of Δvb_{ijl} is compared to the sign of $(vb_{ijl} + \Delta vb_{ijl})$, i.e., the sign of the current incremental deflection is compared to the sign of the current total deflection. If these are equal, then loading is occurring. (This may be in either the upper right hand or lower left-hand quadrants in Figure 4, but is always proceeding away from the origin O.) Then the magnitude of the total deflection is compared to the magnitude of $\overline{vb}_{ijl}$. This is the deflection corresponding to point A of Figure 4, except that it is initially set to zero. Therefore the center path termed "LOADING" will be followed initially. KR is read from an input table and ΔFM_{ijkl} is computed.

When point A of Figure 4 is reached and unloading begins, the sign of Δvb_{ijl} will not be equal to the sign of $(vb_{ijl} + \Delta vb_{ijl})$. The left-hand branch of Figure 5 will then be followed. The first time through this branch, $\overline{vb}_{ijl}$ is set equal to the last vb_{ijl}, which is point A of Figure 4. Then KR is set equal to 1 for the unloading and ΔFM_{ijkl} is computed. As long as unloading proceeds, the left-hand branch is followed and KR = 1.

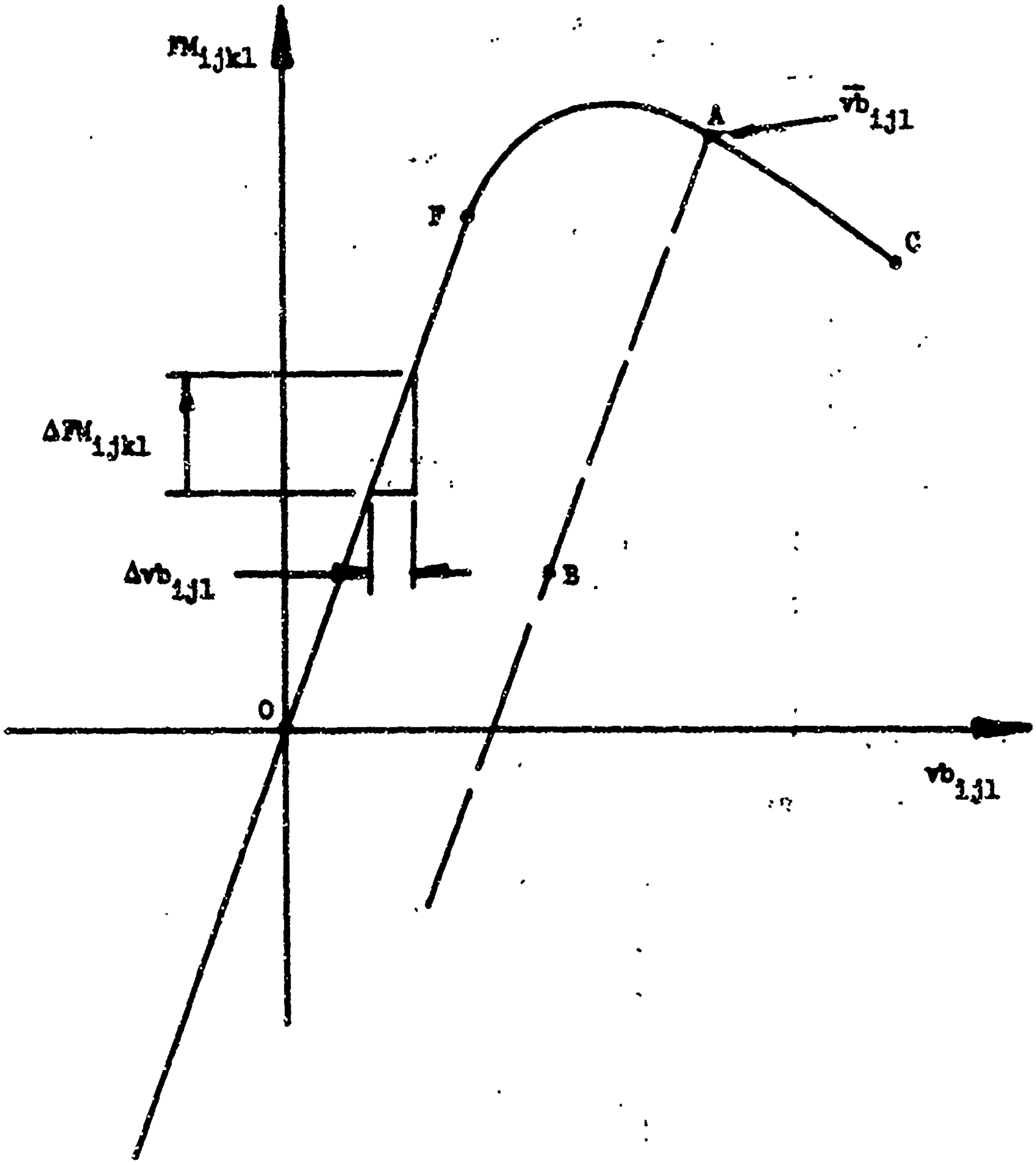
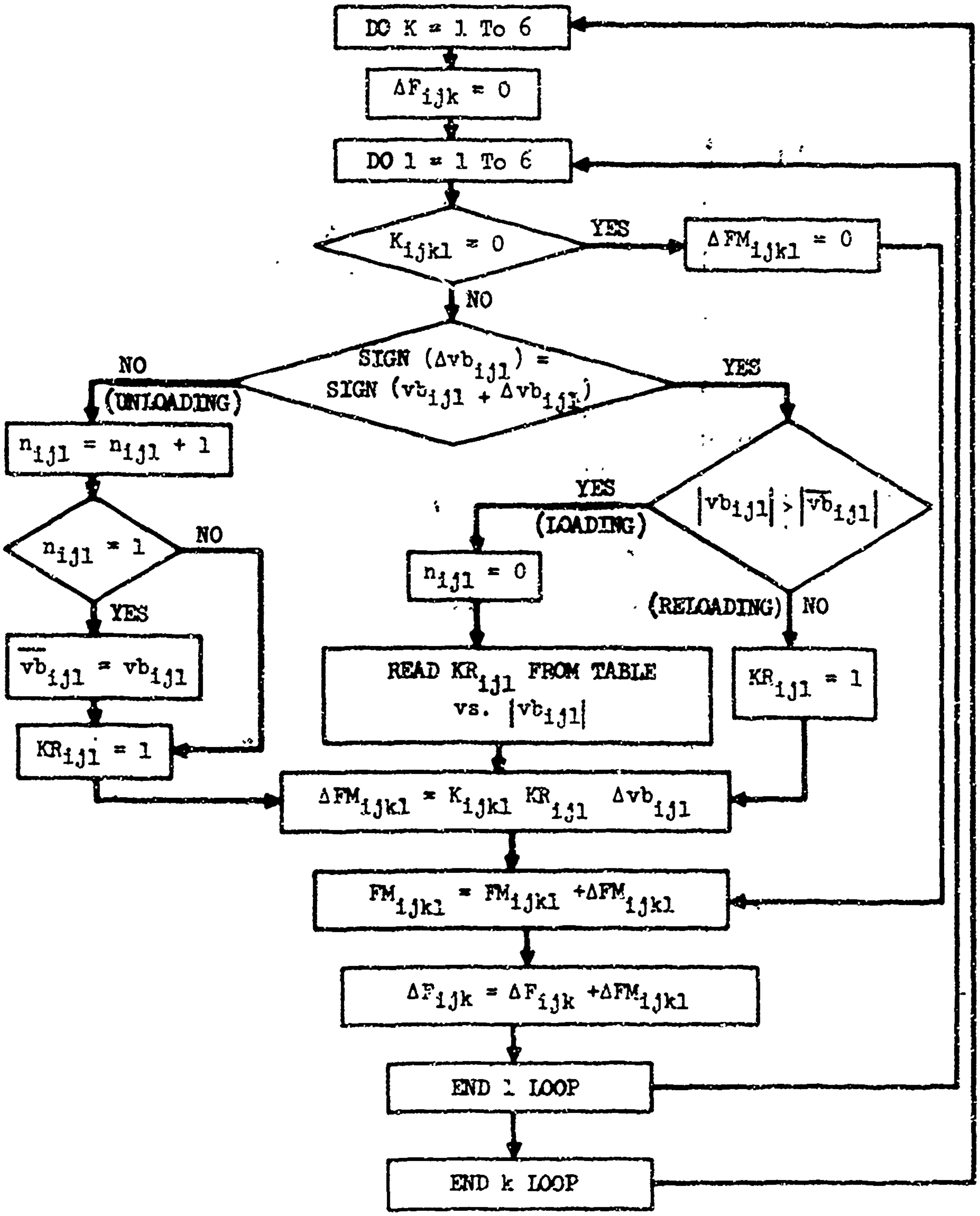

FM_{ijkl}
A
$\bar{vb}_{ijl}$
F
C
ΔFM_{ijkl}
Δvb_{ijl}
B
O
vb_{ijl}

Figure 4. Loading - Unloading Model.



DO K = 1 To 6
$\Delta F_{ijk} = 0$
DO l = 1 To 6
$K_{ijkl} = 0$
YES
$\Delta FM_{ijkl} = 0$
NO
SIGN (Δvb_{ijl}) = SIGN ($vb_{ijl} + \Delta vb_{ijl}$)
NO
(UNLOADING)
YES
$n_{ijl} = n_{ijl} + 1$
$n_{ijl} = 1$
NO
YES
$\overline{vb}_{ijl} = vb_{ijl}$
$KR_{ijl} = 1$
$|vb_{ijl}| > |\overline{vb}_{ijl}|$
YES
(LOADING)
$n_{ijl} = 0$
READ KR_{ijl} FROM TABLE vs. $|vb_{ijl}|$
(RELOADING)
NO
$KR_{ijl} = 1$
$\Delta FM_{ijkl} = K_{ijkl}\ KR_{ijl}\ \Delta vb_{ijl}$
$FM_{ijkl} = FM_{ijkl} + \Delta FM_{ijkl}$
$\Delta F_{ijk} = \Delta F_{ijk} + \Delta FM_{ijkl}$
END l LOOP
END k LOOP

Figure 5. Internal Load Algorithm.

Subsequent reloading occurs along the right-hand branch; the sign of the incremental deflection equals the sign of the total deflection and the magnitude of the deflection is less than $\overline{vb}_{ijl}$. This corresponds to reloading along B-A in Figure 4. For this situation KR is still 1. Finally, once point A is again reached, further loading proceeds along the original curve A-C. The center branch is again followed since $|vb_{ijl}| > |\overline{vb}_{ijl}|$, and KR is again read from the input table.

Equation (26), updating vb_{ijl}, follows immediately after the coding shown in Figure 5; this also includes a test for fracture of beam ij. Thus, if any one of the six vb_{ijl}'s for beam ij is greater in magnitude than an input constant, $v_{MAX_{ijl}}$, beam ij fractures and its internal forces are set to zero for the remainder of the run.

Thus, the algorithm shown in Figure 5 computes the six forces and moments at point j, ΔF_{ijk}, in beam ij axes, according to the sign convention in Figure 3.

3. Internal Forces and Moments Acting on Mass i - The ΔF_{ijk} just computed are transformed into ground axes as follows:

$$\begin{Bmatrix} \Delta X^o_{ij} \\ \Delta Y^o_{ij} \\ \Delta Z^o_{ij} \end{Bmatrix} = [A_i][A_{ij}] \begin{Bmatrix} \Delta X_{ij} \\ \Delta Y_{ij} \\ \Delta Z_{ij} \end{Bmatrix} \tag{28a}$$

where the superscript o refers to ground axes and the right-hand vector is made up of the first three elements of ΔF_{ijk}. Similarly, for the three moments, we have

$$\begin{Bmatrix} \Delta L^o_{ij} \\ \Delta M^o_{ij} \\ \Delta N^o_{ij} \end{Bmatrix} = [A_i][A_{ij}] \begin{Bmatrix} \Delta L_{ij} \\ \Delta M_{ij} \\ \Delta N_{ij} \end{Bmatrix} \tag{28b}$$

Next, a static balance is performed on the beam (since the beam is assumed massless, it has no inertia forces) to obtain the loads at point i, acting on the beam, in ground axes. These are denoted the same as those at j except with a bar. Figure 6 shows the

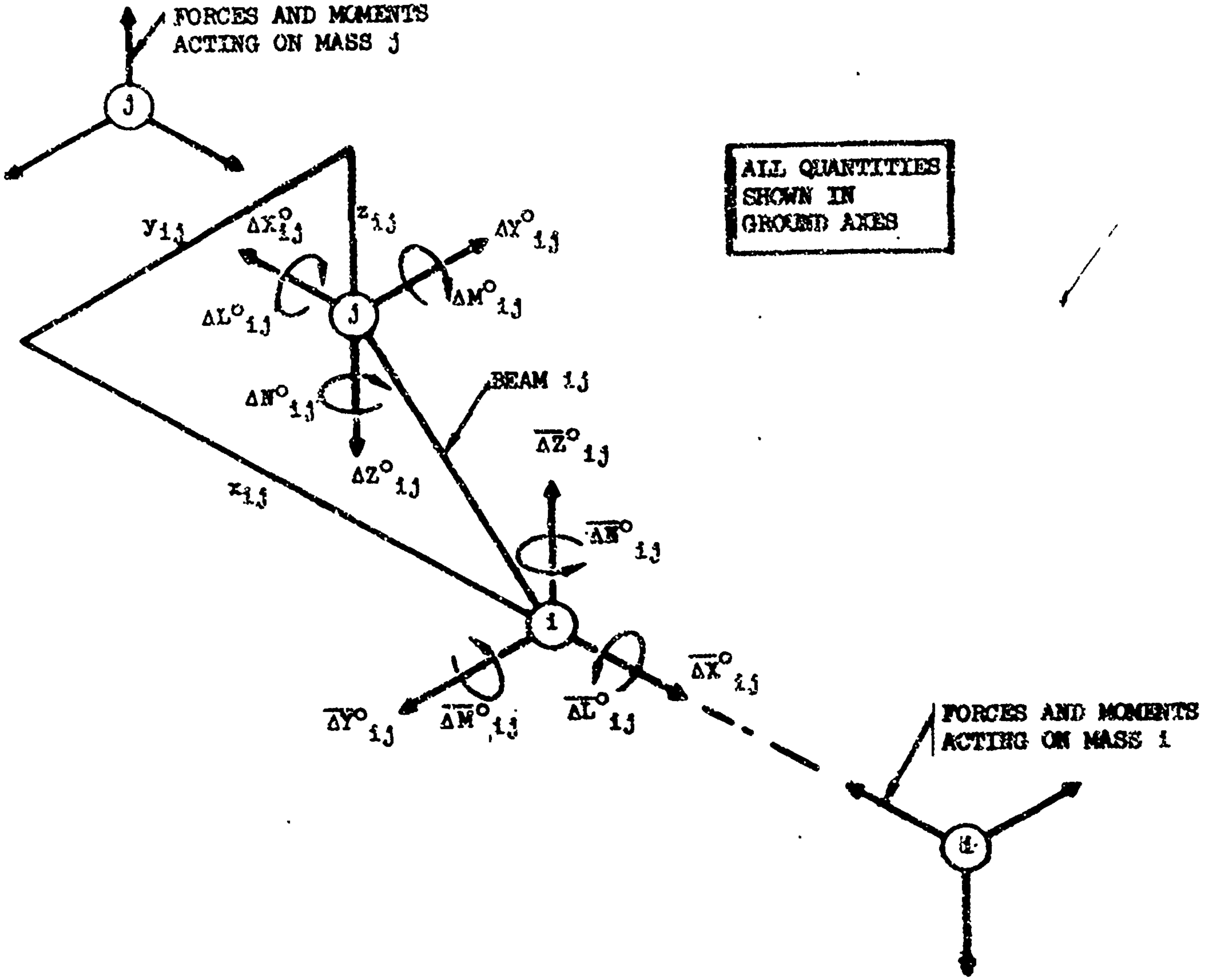

FORCES AND MOMENTS ACTING ON MASS j
j
ALL QUANTITIES SHOWN IN GROUND AXES
y_{ij}
z_{ij}
ΔX^o_{ij}
ΔY^o_{ij}
ΔL^o_{ij}
ΔM^o_{ij}
ΔN^o_{ij}
ΔZ^o_{ij}
BEAM ij
x_{ij}
$\overline{\Delta Z}^o_{ij}$
$\overline{\Delta N}^o_{ij}$
i
$\overline{\Delta X}^o_{ij}$
$\overline{\Delta Y}^o_{ij}$
$\overline{\Delta M}^o_{ij}$
$\overline{\Delta L}^o_{ij}$
FORCES AND MOMENTS ACTING ON MASS i
i

Figure 6. Beam Internal Load Static Balance.

positive loads, in ground axes, at i and j acting on the beam. x_{ij}, y_{ij}, z_{ij} are simply the current distances between j and i in ground axes, shown in Figure 6. These are given by

$$\begin{Bmatrix} x_{ij} \\ y_{ij} \\ z_{ij} \end{Bmatrix} = \begin{Bmatrix} x_j - x_i \\ y_j - y_i \\ z_j - z_i \end{Bmatrix} \tag{29}$$

The static balance equations, from Figure 6, yield simply

$$\begin{Bmatrix} \Delta\overline{X}^o_{ij} \\ \Delta\overline{Y}^o_{ij} \\ \Delta\overline{Z}^o_{ij} \end{Bmatrix} = \begin{Bmatrix} \Delta X^o_{ij} \\ \Delta Y^o_{ij} \\ \Delta Z^o_{ij} \end{Bmatrix} \tag{30a}$$

and

$$\begin{Bmatrix} \Delta\overline{L}^o_{ij} \\ \Delta\overline{M}^o_{ij} \\ \Delta\overline{N}^o_{ij} \end{Bmatrix} = \begin{Bmatrix} \Delta L^o_{ij} \\ \Delta M^o_{ij} \\ \Delta N^o_{ij} \end{Bmatrix} + [T_{ij}] \begin{Bmatrix} \Delta X^o_{ij} \\ \Delta Y^o_{ij} \\ \Delta Z^o_{ij} \end{Bmatrix} \tag{30b}$$

The matrix $[T_{ij}]$ is given simply by

$$[T_{ij}] = \begin{bmatrix} 0 & -z_{ij} & y_{ij} \\ z_{ij} & 0 & -x_{ij} \\ -y_{ij} & x_{ij} & 0 \end{bmatrix} \tag{31}$$

Finally, these loads at point i are transformed back into ith mass axes, since it is in these axes that the internal forces are desired for Euler's equations of motion. (They were transformed from beam to ground axes only to simplify the static balance equations.) Thus, we have

$$\begin{Bmatrix} \Delta X'_{ij} \\ \Delta Y'_{ij} \\ \Delta Z'_{ij} \end{Bmatrix} = [A_i]^T \begin{Bmatrix} \Delta\overline{X}^o_{ij} \\ \Delta\overline{Y}^o_{ij} \\ \Delta\overline{Z}^o_{ij} \end{Bmatrix} \tag{32a}$$

$$\begin{Bmatrix} \Delta L'_{ij} \\ \Delta M'_{ij} \\ \Delta N'_{ij} \end{Bmatrix} = [A_i]^T \begin{Bmatrix} \Delta \bar{L}^o_{ij} \\ \Delta \bar{M}^o_{ij} \\ \Delta \bar{N}^o_{ij} \end{Bmatrix} \tag{32b}$$

The loads acting on mass j, in jth mass axes, are similarly obtained from the loads at point j acting on the beam (equation (28)) in ground axes, by

$$\begin{Bmatrix} \Delta X'_{ji} \\ \Delta Y'_{ji} \\ \Delta Z'_{ji} \end{Bmatrix} = -[A_j]^T \begin{Bmatrix} \Delta X^o_{ij} \\ \Delta Y^o_{ij} \\ \Delta Z^o_{ij} \end{Bmatrix} \tag{33a}$$

$$\begin{Bmatrix} \Delta L'_{ji} \\ \Delta M'_{ji} \\ \Delta N'_{ji} \end{Bmatrix} = -[A_j]^T \begin{Bmatrix} \Delta L^o_{ij} \\ \Delta M^o_{ij} \\ \Delta N^o_{ij} \end{Bmatrix} \tag{33b}$$

The minus sign is necessary because the sense of the loads acting on mass j is opposite the sign convention for the loads acting on mass j (see Figure 6). The minus signs in equations (33) and none in equations (32) are the result of the opposite definitions for the loads acting on the beam at points i and j shown in Figure 6.

The incremental loads from equations (32) and (33) are now summed over time to obtain the total loads:

$$\underset{\substack{\uparrow \\ \text{current}}}{\begin{Bmatrix} X'_{ij} \\ Y'_{ij} \\ Z'_{ij} \\ L'_{ij} \\ M'_{ij} \\ N'_{ij} \end{Bmatrix}} = \underset{\substack{\uparrow \\ \text{previous}}}{\begin{Bmatrix} X'_{ij} \\ Y'_{ij} \\ Z'_{ij} \\ L'_{ij} \\ M'_{ij} \\ N'_{ij} \end{Bmatrix}} + \begin{Bmatrix} \Delta X'_{ij} \\ \Delta Y'_{ij} \\ \Delta Z'_{ij} \\ \Delta L'_{ij} \\ \Delta M'_{ij} \\ \Delta N'_{ij} \end{Bmatrix} \tag{34a}$$

$$\underset{\substack{\uparrow\\ \text{current}}}{\begin{Bmatrix} X'_{ji}\\ Y'_{ji}\\ Z'_{ji}\\ L'_{ji}\\ M'_{ji}\\ N'_{ji} \end{Bmatrix}} = \underset{\substack{\uparrow\\ \text{previous}}}{\begin{Bmatrix} X'_{ji}\\ Y'_{ji}\\ Z'_{ji}\\ L'_{ji}\\ M'_{ji}\\ N'_{ji} \end{Bmatrix}} + \begin{Bmatrix} \Delta X'_{ji}\\ \Delta Y'_{ji}\\ \Delta Z'_{ji}\\ \Delta L'_{ji}\\ \Delta M'_{ji}\\ \Delta N'_{ji} \end{Bmatrix} \qquad (34b)$$

The total internal forces and moments acting on mass i are now computed by summing equations (34) over the second subscript, holding the first subscript constant:

$$X_{I_i} = \sum_{j=1}^{N} X'_{ij} \qquad Y_{I_i} = \sum_{j=1}^{N} Y'_{ij} \qquad Z_{I_i} = \sum_{j=1}^{N} Z'_{ij}$$

$$L_{I_i} = \sum_{j=1}^{N} L'_{ij} \qquad M_{I_i} = \sum_{j=1}^{N} M'_{ij} \qquad N_{I_i} = \sum_{j=1}^{N} N'_{ij} \qquad (35)$$

where N is the total number of masses. As an example, assume a four-mass system fully interconnected. Equation (34a) gives the

F' 12
13
14
23
24
34 loads.

Equation (34b) gives the

F' 21
31
41
32
42
43 loads.

Thus, equation (35) sums over the second subscript, holding the first subscript constant, to obtain the total internal loads from all the beams:

$$F_{I_1} = F'_{12} + F'_{13} + F'_{14}$$

$$F_{I_2} = \boxed{F'_{21}} + F'_{23} + F'_{24}$$

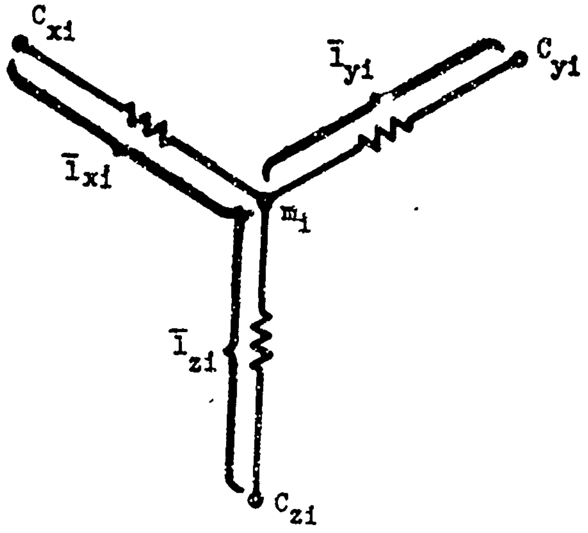
$$F_{I_3} = \boxed{F'_{31} + F'_{32}} + F'_{34}$$

$$F_{I_4} = \boxed{F'_{41} + F'_{42} + F'_{43}}$$

The circled terms come from equation (34b); the others, from (34a). $F'_{ij} = 0$ for $i = j$ (there is no beam from i to i). The above scheme is used so that the loads at each end of the beam ij are not computed twice (once for mass i and again for mass j). Equation (35) gives the desired total internal loads to be used later to determine the total loads acting on mass i.

Crash (External) Forces and Moments (X_{ci}, Y_{ci}, Z_{ci}, L_{ci}, M_{ci}, and N_{ci})

The crash forces result from the compression of external springs radiating from each mass, when these springs contact the ground plane (z = 0). The following sketch shows the three springs radiating outward from mass i:



The free (uncompressed) lengths of the three springs are denoted $\bar{\ell}_{xi}$, $\bar{\ell}_{yi}$, and $\bar{\ell}_{zi}$. These springs lie along the body axes for the ith mass. $\bar{\ell}_{xi}$, $\bar{\ell}_{yi}$, and $\bar{\ell}_{zi}$ are input either positive or negative, depending upon whether the spring radiates outward along the positive or negative body axis. Those shown above are all positive springs. C_{xi}, C_{yi}, and C_{zi} are the end points of the fully extended springs. Only data for those springs desired in the analysis need be input; if no spring is input, its crash forces are set to zero. Typically, only those masses at the extremities of the vehicle likely to contact the ground would have crash springs. The intent of these springs is to represent crushable external structure such as found on the lower fuselage and nose sections.

The first step in the calculation is to determine which of the C_{xi}, C_{yi}, and C_{zi} spring end points are below the ground. Only these springs are further analyzed to determine their crash forces. For these springs, the spring compression along the spring axis is determined, as well as the compression velocity and the ground contact point velocity. Then the spring force along the spring axis is calculated, from which the vertical load in ground axes at the ground contact point is obtained. From this vertical load and input friction coefficients, the ground drag load is computed. The direction of this load is opposite the ground contact point velocity vector. Finally, the three forces at the ground contact point are rotated into ith mass body axes, and the resulting forces and moments at mass i are calculated.

1. Spring Compression - Figure 7 shows a typical spring contacting the ground at an oblique angle. Point C_i' is the ground contact point. Treating the fully extended spring as a vector, that portion of the vector below the ground represents the spring compression. This is the distance from point C_i' to point C_i. The coordinates of point C_i, in ground axes, are given simply by

$$\begin{bmatrix} xc_{xi} & xc_{yi} & xc_{zi} \\ yc_{xi} & yc_{yi} & yc_{zi} \\ zc_{xi} & zc_{yi} & zc_{zi} \end{bmatrix} = \begin{bmatrix} x_i & x_i & x_i \\ y_i & y_i & y_i \\ z_i & z_i & z_i \end{bmatrix} + [A_i] \begin{bmatrix} \bar{\ell}_{xi} & & \\ & \bar{\ell}_{yi} & \\ & & \bar{\ell}_{zi} \end{bmatrix} \tag{36}$$

The above equation gives the coordinates of all three C_i for mass i; these points are denoted C_{xi}, C_{yi}, and C_{zi}. Figure 7 shows only one of the three springs, so the nomenclature in Figure 7 is

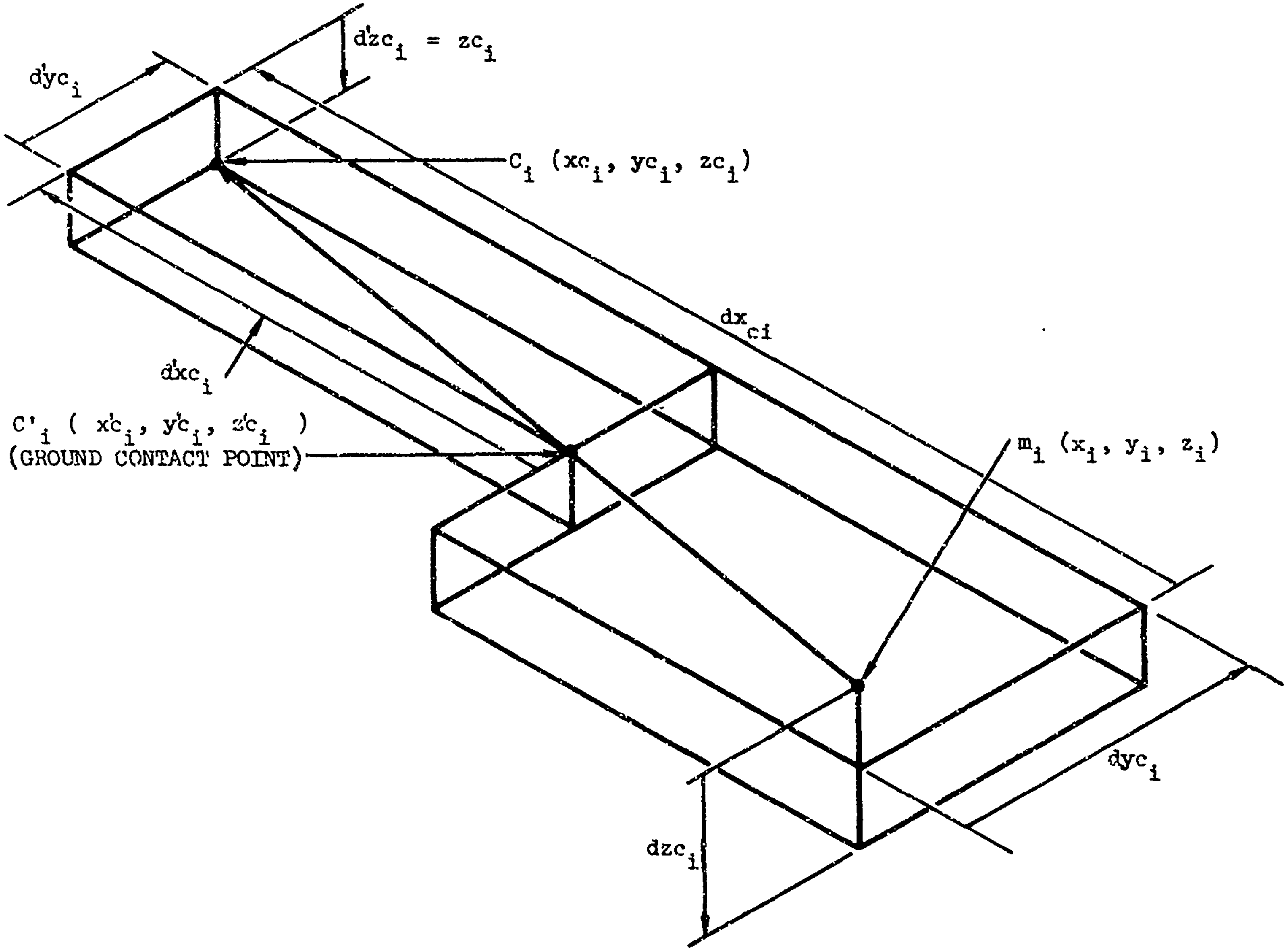

$d'zc_i = zc_i$
$d'yc_i$
$C_i\ (xc_i,\ yc_i,\ zc_i)$
dx_{ci}
$d'xc_i$
$C'_i\ (x'c_i,\ y'c_i,\ z'c_i)$
(GROUND CONTACT POINT)
$m_i\ (x_i,\ y_i,\ z_i)$
dyc_i
dzc_i

Figure 7. External Spring Compression Geometry.

not subscripted to indicate whether an x, y or z spring is shown. The second term in the above equation is equal to dx_{ci}, dy_{ci}, and dz_{ci} in Figure 7:

$$\begin{bmatrix} dxc_{xi} & dxc_{yi} & dxc_{zi} \\ dyc_{xi} & dyc_{yi} & dyc_{zi} \\ dzc_{xi} & dzc_{yi} & dzc_{zi} \end{bmatrix} = [A_i] \begin{bmatrix} \bar{l}_{xi} & & \\ & \bar{l}_{yi} & \\ & & \bar{l}_{zi} \end{bmatrix} \qquad (37)$$

The dxc_i', dyc_i', and dzc_i' in Figure 7 can be determined from proportionality considerations as

$$\begin{Bmatrix} dxc'_{xi} \\ dyc'_{xi} \\ dzc'_{xi} \end{Bmatrix} = \frac{zc_{xi}}{dzc_{xi}} \begin{Bmatrix} dxc_{xi} \\ dyc_{xi} \\ dzc_{xi} \end{Bmatrix} \qquad (38)$$

and similarly for the y and z springs,

$$\begin{Bmatrix} dxc'_{yi} \\ dyc'_{yi} \\ dzc'_{yi} \end{Bmatrix} = \frac{zc_{yi}}{dzc_{yi}} \begin{Bmatrix} dxc_{yi} \\ dyc_{yi} \\ dzc_{yi} \end{Bmatrix}$$

$$\begin{Bmatrix} dxc'_{zi} \\ dyc'_{zi} \\ dzc'_{zi} \end{Bmatrix} = \frac{zc_{zi}}{dzc_{zi}} \begin{Bmatrix} dxc_{zi} \\ dyc_{zi} \\ dzc_{zi} \end{Bmatrix} \qquad (38)$$

From these ground axes components of the vector from C_i' to C_i, the magnitude of this vector (equal to the spring compression) is given simply by

$$s_{xi} = \left[(dxc'_{xi})^2 + (dyc'_{xi})^2 + (dzc'_{xi})^2\right]^{1/2}$$

$$s_{yi} = \left[(dxc'_{yi})^2 + (dyc'_{yi})^2 + (dzc'_{yi})^2\right]^{1/2} \qquad (39)$$

$$s_{zi} = \left[(dxc'_{zi})^2 + (dyc'_{zi})^2 + (dzc'_{zi})^2\right]^{1/2}$$

In order to simplify the notation, the following vectors and matrices are defined ($i = 1, 2, \ldots, N$ indicates the mass; $j = 1,2,3$ indicates the direction; $k = 1,2,3$ indicates which spring):

$$\bar{l}_{ik} \overset{\Delta}{=} \begin{Bmatrix} \bar{l}_{xi} \\ \bar{l}_{yi} \\ \bar{l}_{zi} \end{Bmatrix} \quad va_{ij} \overset{\Delta}{=} \begin{Bmatrix} x_i \\ y_i \\ z_i \end{Bmatrix} \quad s_{ik} \overset{\Delta}{=} \begin{Bmatrix} s_{xi} \\ s_{yi} \\ s_{zi} \end{Bmatrix} \qquad (40)$$

$$dvc_{ijk} \overset{\Delta}{=} j \underset{k}{\begin{bmatrix} dxc_{xi} & dxc_{yi} & dxc_{zi} \\ dyc_{xi} & dyc_{yi} & dyc_{zi} \\ dzc_{xi} & dzc_{yi} & dzc_{zi} \end{bmatrix}} \qquad (41)$$

$$vc_{ijk} \overset{\Delta}{=} j \underset{k}{\begin{bmatrix} xc_{xi} & xc_{yi} & xc_{zi} \\ yc_{xi} & yc_{yi} & yc_{zi} \\ zc_{xi} & zc_{yi} & zc_{zi} \end{bmatrix}} \qquad (42)$$

$$dvc'_{ijk} \overset{\Delta}{=} j \underset{k}{\begin{bmatrix} dxc'_{xi} & dxc'_{yi} & dxc'_{zi} \\ dyc'_{xi} & dyc'_{yi} & dyc'_{zi} \\ dzc'_{xi} & dzc'_{yi} & dzc'_{zi} \end{bmatrix}} \qquad (43)$$

Using this nomenclature, equations (36) through (39) become simply

$$vc_{ijk} = va_{ij} + dvc_{ijk} \qquad (44)$$

$$dvc_{ijk} = A_{ijk}\bar{l}_{ik} \qquad (45)$$

$$dvc'_{ijk} = \frac{vc_{i3k}}{dvc_{i3k}} dvc_{ijk} \qquad (46)$$

$$s_{ik} = \left[\sum_{j=1}^{3} \left(dvc'_{ijk}\right)^2\right]^{1/2} \qquad (47)$$

We shall also require the spring compression velocity, $\dot{s}_{ik}$. This is given by differentiating equation (47) as

$$\dot{s}_{ik} = \frac{1}{2s_{ik}} \sum_{j=1}^{3} 2\ dvc'_{ijk}\left(\dot{dvc}'_{ijk}\right) \qquad (48)$$

where the last term is obtained from (46) as

$$\dot{dvc}'_{ijk} = \frac{vc_{i3k}}{dvc_{i3k}}\dot{dvc}_{ijk} + dvc_{ijk}\frac{dvc_{i3k}\dot{vc}_{i3k} - vc_{i3k}\dot{dvc}_{i3k}}{(dvc_{i3k})^2} \qquad (49)$$

The time derivatives in (49) are given by

$$\dot{dvc}_{ijk} = \dot{A}_{ijk}\bar{l}_{ik} \qquad j = 1,2,3 \qquad (50)$$

$$\dot{vc}_{i3k} = \dot{z}_i + \dot{dvc}_{i3k} \qquad (51)$$

2. Ground Contact Point Velocity - The next computation required is to determine the ground contact point velocity in the ground plane. This is necessary to determine the line of action of the ground plane drag load, which is opposite to the contact point velocity vector. The velocity of point C' with respect to ground is given in vector notation as

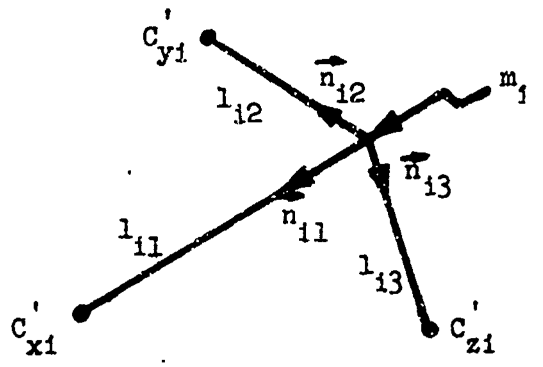
$$\overset{O \longrightarrow C'}{V} = \overset{m_i \longrightarrow C'}{V} + \overset{O \longrightarrow m_i}{V} \qquad (52)$$

where $\overset{O \longrightarrow C'}{V}$ = velocity of C' with respect to ground

$\overset{m_i \longrightarrow C'}{V}$ = velocity of C' with respect to point m_i

$\overset{O \longrightarrow m_i}{V}$ = velocity of point m_i with respect to ground

Define $\vec{n}_{ik}$ as a unit vector radiating from m_i parallel to the ith mass body fixed axes, as shown in the following sketch:



Also define l_{ik} as the length from m_i to point C'. This is given by

$$l_{ik} = \text{SIGN}(\bar{l}_{ik})\left|\left|\bar{l}_{ik}\right| - s_{ik}\right| \tag{53}$$

This form is used so that l_{ik} has the same sign as the input $\bar{l}_{ik}$, which as mentioned earlier can be negative to allow springs in the negative direction of the body axes. Returning to equation (52), $\overset{O \longrightarrow m_i}{V}$ is given by

$$\overset{O \longrightarrow m_i}{V} = \dot{x}_i\bar{n}_x + \dot{y}_i\bar{n}_y + \dot{z}_i\bar{n}_z \tag{54}$$

where $\bar{n}_x$, $\bar{n}_y$, and $\bar{n}_z$ are unit vectors fixed in the ground coordinate system. $\overset{m_i \longrightarrow C'}{V}$ is given by

$$m_i \underset{V}{\longrightarrow} C' = -\dot{s}_{ik}\bar{n}_{ik} + \overset{0 \longrightarrow m_i}{\omega} \times l_{ik}\bar{n}_{ik} \qquad k = 1,2,3 \qquad (55)$$

where $\overset{0 \longrightarrow m_i}{\omega}$ is the angular velocity vector of m_i with respect to the ground. This is defined as

$$\overset{0 \longrightarrow m_i}{\omega} \triangleq p_i\vec{n}_{i1} + q_i\vec{n}_{i2} + r_i\vec{n}_{i3} \qquad (56)$$

in body fixed axes. Equation (55), therefore, becomes

$$m_i \underset{V}{\longrightarrow} C' = -\dot{s}_{ik}\bar{n}_{ik} + (p_i\vec{n}_{i1} + q_i\vec{n}_{i2} + r_i\vec{n}_{i3}) \times l_{ik}\vec{n}_{ik} \qquad (57)$$

$$k = 1,2,3$$

Expanding the cross product and combining terms, we obtain

$$m_i \underset{V}{\longrightarrow} C' = \begin{array}{ll} -\dot{s}_{i1}\bar{n}_{i1} + r_i l_{i1}\bar{n}_{i2} - q_i l_{i1}\bar{n}_{i3} & k = 1 \\ -r_i l_{i2}\bar{n}_{i1} - \dot{s}_{i2}\bar{n}_{i2} + p_i l_{i2}\bar{n}_{i3} & k = 2 \\ q_i l_{i3}\bar{n}_{i1} - p_i l_{i3}\bar{n}_{i2} - \dot{s}_{i3}\bar{n}_{i3} & k = 3 \end{array} \qquad (58)$$

Denoting the transpose of the above terms by the matrix $[pl_i]$, we can obtain $m_i \underset{V}{\longrightarrow} C'$ in ground axes simply by premultiplying the kth column of $[pl_i]$ by $[A_i]$:

$$\underset{\text{ground axes}}{m_i \underset{V}{\longrightarrow} C'} = [A_i]\begin{Bmatrix} pl_{i1k} \\ pl_{i2k} \\ pl_{i3k} \end{Bmatrix} \qquad k = 1,2,3 \qquad (59)$$

Combining (54) and (59), recalling definition (40) for va_{ij}, we obtain the desired contact velocities as simply

$$\dot{v}cp_{ijk} = \dot{v}a_{ij} + \sum_{l=1}^{3} A_{ijl}pl_{ilk} \qquad \begin{array}{l} i = 1,2,\ldots,N \\ j = 1,2,3, \\ k = 1,2,3 \end{array} \tag{60}$$

where

$$[pl_i] = l \underset{k}{\begin{bmatrix} -\dot{s}_{i1} & -r_i l_{i2} & q_i l_{i3} \\ r_i l_{i1} & -\dot{s}_{i2} & -p_i l_{i3} \\ -q_i l_{i1} & p_i l_{i2} & -\dot{s}_{i3} \end{bmatrix}} \tag{61}$$

Equation (60) gives the desired velocities of the pavement contact points, in ground axes. Only the x and y components are used later; the z component should be zero. Recall that i refers to the ith mass, j the jth direction, and k the kth spring or contact point.

3. External Spring Axial Force - This section discusses the calculation of the external spring force along the spring axis. The axial force in the spring, denoted $FSPO_{ik}$, is input as a tabular function of the spring compression s_{ik}. As with the internal forces, unloading along an elastic line is included. However, unlike the internal forces, an extension load is not allowed; positive $FSPO_{ik}$ is a compressive load acting at the ground contact point along the axis of spring ik.

Figure 8 illustrates a typical load-stroke curve for an external spring. The basic loading curve O-A-B-C is input in tabular form vs s_{ik}, and this curve is followed during the initial loading. During unloading, say, from point B, the dashed line B-D is followed. The slope of this line, ke_{ik}, is input to the program. During subsequent reloading, curve D-E-F is followed; this is merely the original curve transposed to the right by the amount s''_{ik}. The dashed coordinate system always contains the original input curve, but the location of the system varies with each unloading cycle. Once $\dot{s}_{ik}$ goes negative, $\bar{s}_{ik}$ and $\overline{FSPO}_{ik}$ are assigned the latest values of s_{ik} and $FSPO_{ik}$ (the values at point B). These barred quantities are then used with ke_{ik} to define s''_{ik}. The barred quantities are initially set to zero, so that until the first unloading, the dashed coordinates coincide with the solid coordinates.

When the spring compresses beyond point C, a stiff spring ke_{ik} takes effect (this is the same spring constant as is used for unloading), as shown by line C-F-G in Figure 8. This is intended

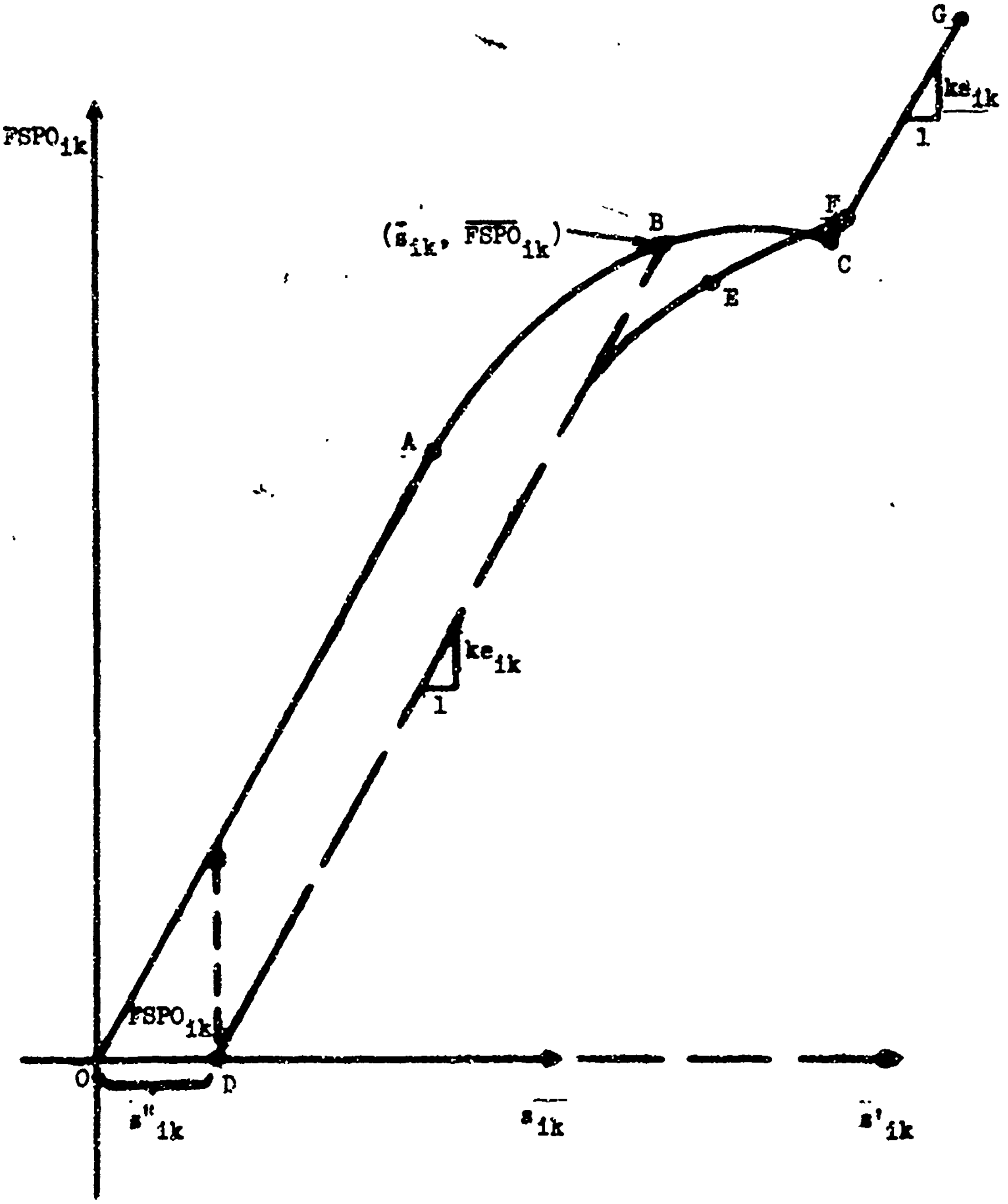

G
ks_{ik}
1
$FSPO_{ik}$
F
B
$(\bar{s}_{ik}, \overline{FSPO}_{ik})$
C
E
A
ke_{ik}
1
$FSPO_{ik}$
O
D
s''_{ik}
$\bar{s}_{ik}$
s'_{ik}

Figure 8. External Spring Load-Stroke Curve.

to represent the finite crushing distance available, beyond which the spring becomes very stiff. There is no fracture of an external spring, as there is with the internal beams.

The flow diagram for the calculation of the spring force $FSPO_{ik}$ is shown in Figure 9. The calculations are performed within nested i and k loops. The first test on SP_{ik} is to tell if there is an external spring. If there is, then vc_{3k} is checked. This is zc_{ik}, the vertical position of the end of spring ik. If this is greater than zero, then there will be a spring force. The next test is to see if $s_{ik} > S_{F_{ik}}$, the final value input in the table of s_{ik} vs $FSPO_{ik}$ (point C in Figure 8). If it is greater, the force is computed as $FSPOF_{ik}$ plus an increment due to the ke_{ik} spring. Then if this is less than zero, it is set to zero.

If $s_{ik} < s_{Fik}$, then we test BS_{ik}. This is simply an indicator to see if the bottoming spring has been hit ($BS_{ik} = 0$ initially). If it has been hit ($BS_{ik} = 1$), then from then on the force is computed along line C-F-G, and its extension downward. If the bottoming spring has not been hit, then s''_{ik} is computed from $\bar{s}_{ik}$ and $\overline{FSPO}_{ik}$. During the first loading cycle these will be zero, but after unloading they will be nonzero. S'_{ik} is then calculated, and $FSPO_{ik}$ is read from the input table unless $s'_{ik} < 0$, in which case $FSPO_{ik} = 0$. Then $\dot{s}_{ik}$ is checked to see if loading or unloading is taking place. The first time unloading occurs, $nn_{ik} = 0$ and $\overline{FSPO}_{ik}$ and $\bar{s}_{ik}$ are assigned the latest values of $FSPO_{ik}$ and s_{ik}. These correspond to point B in Figure 8. During continued unloadings, $nn_{ik} \neq 0$ so these values are not reassigned until a loading cycle occurs and nn_{ik} is reset to zero. This completes the calculation of the axial spring force $FSPO_{ik}$.

4. Crash Forces at Ground Contact Point - The three components of the ground interaction force at the ground contact point are denoted by $XVOC_{ijk}$, where, as before, i refers to the ith mass, j to the force direction, and k to the kth spring for mass i. First the component of the axial spring force perpendicular to the ground is computed. This is positive upward acting on the spring. This is given simply by resolving $FSPO_{ik}$ into ground axes and retaining only the vertical component. Thus, we have

$$XVOC_{i3k} = A_{i3k} FSPO_{ik} \qquad k = 1,2,3 \qquad (62)$$

since $FSPO_{ik}$ acts along the kth body axis for mass i. The ground plane components of the axial force $FSPO_{ik}$ are ignored, since these values are next computed on the assumption that they are

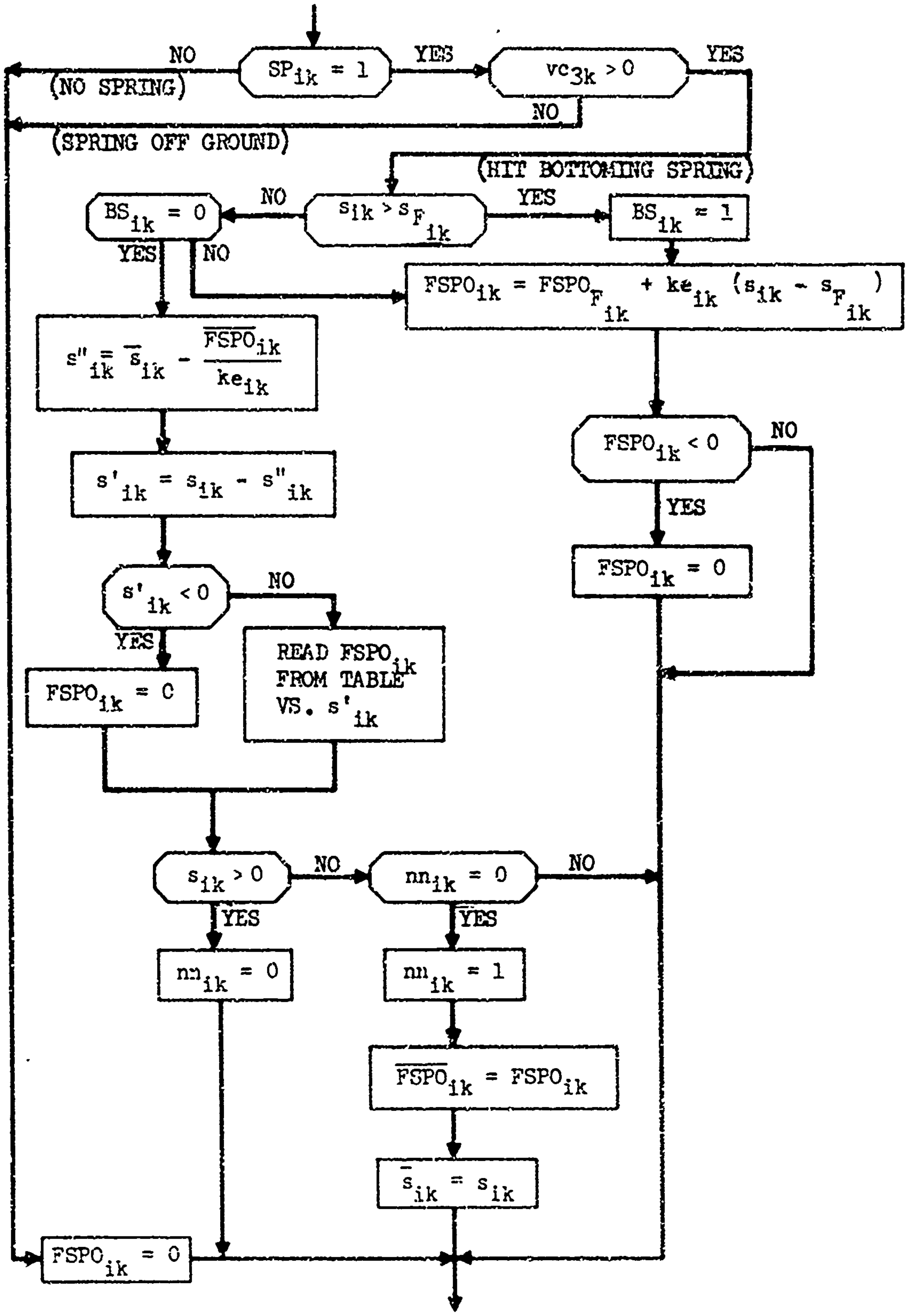
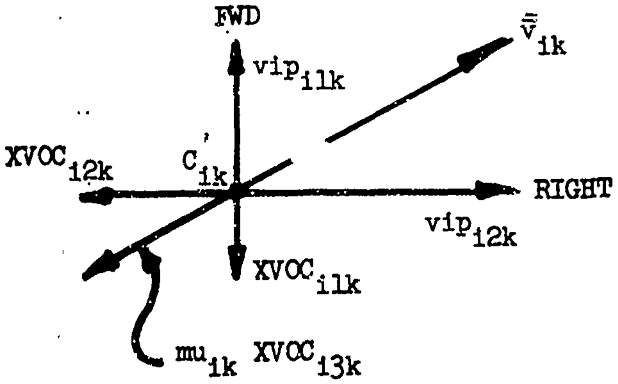

NO
$SP_{ik} = 1$
YES
$vc_{3k} > 0$
YES
(NO SPRING)
NO
(SPRING OFF GROUND)
(HIT BOTTOMING SPRING)
$BS_{ik} = 0$
NO
$s_{ik} > s_{F_{ik}}$
YES
$BS_{ik} = 1$
YES
NO
$FSPO_{ik} = FSPO_{F_{ik}} + ke_{ik}(s_{ik} - s_{F_{ik}})$
$s''_{ik} = \bar{s}_{ik} - \frac{\overline{FSPO}_{ik}}{ke_{ik}}$
$FSPO_{ik} < 0$
NO
YES
$s'_{ik} = s_{ik} - s''_{ik}$
$FSPO_{ik} = 0$
$s'_{ik} < 0$
NO
YES
$FSPO_{ik} = 0$
READ $FSPO_{ik}$ FROM TABLE VS. s'_{ik}
$s_{ik} > 0$
NO
$nn_{ik} = 0$
NO
YES
YES
$nn_{ik} = 0$
$nn_{ik} = 1$
$\overline{FSPO}_{ik} = FSPO_{ik}$
$\bar{s}_{ik} = s_{ik}$
$FSPO_{ik} = 0$

Figure 9. External Load Calculation.

functions of the ground-spring friction coefficient. The ground plane velocity vector, from equation (60), has the magnitude

$$\bar{\bar{v}}_{ik} = \left[(\dot{vcp}_{i1k})^2 + (\dot{vcp}_{i2k})^2\right]^{1/2} \tag{63}$$

This is shown in the following sketch, a plan view looking downward at ground contact point C'_{ik}:



The magnitude of the resultant ground plane load is assumed to be given by $mu_{ik}XVOC_{i3k}$, i.e., an input friction coefficient times the vertical load perpendicular to the ground plane. The direction of this ground plane load is assumed to be opposite to the contact point velocity vector $\bar{\bar{v}}_{ik}$, as shown in the above sketch. Therefore, the drag and side loads at point C'_{ik}, in ground axes, are given by

$$XVOC_{ijk} = mu_{ik}XVOC_{i3k}\frac{\dot{vcp}_{ijk}}{\bar{\bar{v}}_{ik}} \qquad j = 1,2 \tag{64}$$

These are illustrated in the above sketch. These forces are now resolved back into ith mass body axes; these resolved forces are denoted by FSP_{ijk}.

We have

$$\begin{Bmatrix} FSP_{i1k} \\ FSP_{i2k} \\ FSP_{i3k} \end{Bmatrix} = -[A_i]^T \begin{Bmatrix} XVOC_{i1k} \\ XVOC_{i2k} \\ XVOC_{i3k} \end{Bmatrix} \quad k = 1,2,3 \tag{65}$$

The minus sign is used so that these forces have the same sense as the basic body axis convention, since $XVOC_{ijk}$ were positive aft, left and upward.

These forces are illustrated in Figure 10.

5. Crash Forces and Moments at Point m_i - Now we are in a position to obtain the crash forces and moments acting at point m_i. Figure 10 shows these forces and moments, which are just the resultant of the FSP_{ijk} also shown in Figure 10; i.e., the FSP_{ijk} are just moved to point m_i and compensating moments at m_i added. Thus, we have

$$\begin{aligned} X_{c_i} &= \sum_{k=1}^{3} FSP_{i1k} \\ Y_{c_i} &= \sum_{k=1}^{3} FSP_{i2k} \qquad i = 1,2,\ldots,N \\ Z_{c_i} &= \sum_{k=1}^{3} FSP_{i3k} \end{aligned} \tag{66a}$$

$$\begin{aligned} L_{c_i} &= FSP_{i32}\, l_{i2} - FSP_{i23}\, l_{i3} \\ M_{c_i} &= FSP_{i13}\, l_{i3} - FSP_{i31}\, l_{i1} \qquad i = 1,2,\ldots,N \\ N_{c_i} &= FSP_{i21}\, l_{i1} - FSP_{i12}\, l_{i2} \end{aligned} \tag{66b}$$

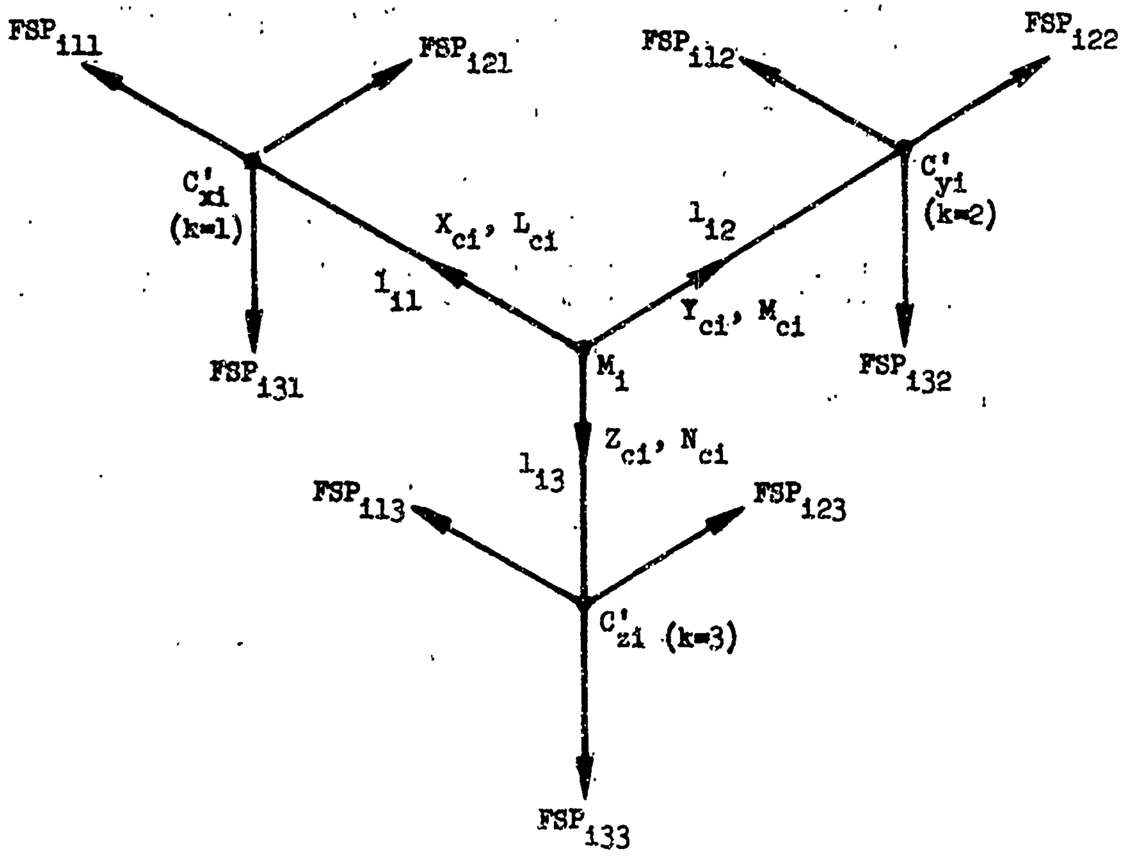

FSP$_{i11}$
FSP$_{i21}$
FSP$_{i12}$
FSP$_{i22}$
C'$_{xi}$
(k=1)
X$_{ci}$, L$_{ci}$
l$_{i2}$
C'$_{yi}$
(k=2)
l$_{i1}$
Y$_{ci}$, M$_{ci}$
FSP$_{i31}$
M$_i$
FSP$_{i32}$
Z$_{ci}$, N$_{ci}$
l$_{i3}$
FSP$_{i13}$
FSP$_{i23}$
C'$_{zi}$ (k=3)
FSP$_{i33}$

Figure 10. Crash Forces and Moments.

The l_{ik} are from equation (53); recall that they may be plus or minus to allow for springs in the negative direction of the mass body axes. Figure 10 shows all l_{ik} positive. Equations (66) give the desired crash forces acting at m_i in ith mass body axes.

Damping Forces and Moments (Internal) (X_{D_i}, Y_{D_i}, Z_{D_i}, L_{D_i}, M_{D_i}, and N_{D_i})

The damping forces and moments are internal loads in that they act at masses i and j due to the damping associated with beam ij. This damping results from the friction of the joints in the structure that comprises beam ij, and from the damping inherent in the structural material. For simplicity, the damping is modeled as linear (viscous). Experience with the program indicates that this structural damping, although believed to be small, must be represented in order to control high-frequency structural vibrations.

First, for beam ij, the linear and angular velocities of point j with respect to point i are computed in beam ij axes. These are then premultiplied by a 6 x 6 diagonal damping coefficient matrix to obtain damping forces and moments in beam axes. The damping loads at point j in beam axes are then transformed into ground axes, and the loads at point i in ground axes are computed from static equilibrium equations. Then, the loads at i and j are transformed into ith and jth mass body axes, respectively. Finally, for each mass, the contributions from the various beams that attach to that mass are summed to obtain the total damping loads for the mass. The damping forces calculated are instantaneous total values, rather than incremental loads as were used for the internal loads.

The linear velocities of point j with respect to point i, resolved into beam ij axes, are clearly given by

$$\begin{Bmatrix} \dot{x}b_{ij} \\ \dot{y}b_{ij} \\ \dot{z}b_{ij} \end{Bmatrix} = [A_{ij}]^T \left[[A_i]^T [A_j] \begin{Bmatrix} u_j \\ v_j \\ w_j \end{Bmatrix} - \begin{Bmatrix} u_i \\ v_i \\ w_i \end{Bmatrix} \right] \qquad (67a)$$

where u_i, v_i, and w_i are the body axes components of the absolute linear velocity of mass i. Similarly for the angular velocities, we have

$$\begin{Bmatrix} \dot{\phi}b_{ij} \\ \dot{\theta}b_{ij} \\ \dot{\psi}b_{ij} \end{Bmatrix} = [A_{ij}]^T \left[[A_i]^T[A_j] \begin{Bmatrix} p_j \\ q_j \\ r_j \end{Bmatrix} - \begin{Bmatrix} p_i \\ q_i \\ r_i \end{Bmatrix} \right] \tag{67b}$$

where p_i, q_i, and r_i are the body axes components of the absolute angular velocity of mass i. The damping forces, in beam axes, are now computed simply as

$$\left\{ FD_{ij} \right\} = \left\lceil C_{ij} \right\rfloor \left\{ \dot{v}b_{ij} \right\} \tag{68}$$

where the velocity and load vectors $\left\{ \dot{v}b_{ij} \right\}$ and $\left\{ FD_{ij} \right\}$ are defined as

$$\left\{ \dot{v}b_{ij} \right\} \triangleq \begin{Bmatrix} \dot{x}b_{ij} \\ \dot{y}b_{ij} \\ \dot{z}b_{ij} \\ \dot{\phi}b_{ij} \\ \dot{\theta}b_{ij} \\ \dot{\psi}b_{ij} \end{Bmatrix} \qquad \left\{ FD_{ij} \right\} \triangleq \begin{Bmatrix} X_{Dij} \\ Y_{Dij} \\ Z_{Dij} \\ L_{Dij} \\ M_{Dij} \\ N_{Dij} \end{Bmatrix} \tag{69}$$

The 6 x 6 damping coefficient matrix $\left\lceil C_{ij} \right\rfloor$ is a diagonal matrix, since it is felt that the actual damping values are so poorly known that the inclusion of off-diagonal terms is not justified. The calculation of the $\left\lceil C_{ij} \right\rfloor$ matrix is discussed later.

The loads in equation (68) are those acting at mass j, in beam ij axes. These are transformed to ground axes as follows:

$$\begin{Bmatrix} X^{o}_{Dij} \\ Y^{o}_{Dij} \\ Z^{o}_{Dij} \end{Bmatrix} = [A_i][A_{ij}] \begin{Bmatrix} X_{Dij} \\ Y_{Dij} \\ Z_{Dij} \end{Bmatrix} \tag{70a}$$

and

$$\begin{Bmatrix} L^{o}_{Dij} \\ M^{o}_{Dij} \\ N^{o}_{Dij} \end{Bmatrix} = [A_i][A_{ij}] \begin{Bmatrix} L_{Dij} \\ M_{Dij} \\ N_{Dij} \end{Bmatrix} \tag{70b}$$

Now the forces and moments at point i, in ground axes, are computed from static equilibrium in the same manner as in equation (30):

$$\begin{Bmatrix} \bar{X}^{o}_{Dij} \\ \bar{Y}^{o}_{Dij} \\ \bar{Z}^{o}_{Dij} \end{Bmatrix} = \begin{Bmatrix} X^{o}_{Dij} \\ Y^{o}_{Dij} \\ Z^{o}_{Dij} \end{Bmatrix} \tag{71a}$$

and

$$\begin{Bmatrix} \bar{L}^{o}_{Dij} \\ \bar{M}^{o}_{Dij} \\ \bar{N}^{o}_{Dij} \end{Bmatrix} = \begin{Bmatrix} L^{o}_{Dij} \\ M^{o}_{Dij} \\ N^{o}_{Dij} \end{Bmatrix} + [T_{ij}] \begin{Bmatrix} X^{o}_{Dij} \\ Y^{o}_{Dij} \\ Z^{o}_{Dij} \end{Bmatrix} \tag{71b}$$

Now, transforming these loads into ith mass axes gives the loads acting on mass m_i due to beam ij, in ith mass body axes.

$$\begin{Bmatrix} X'_{Dij} \\ Y'_{Dij} \\ Z'_{Dij} \end{Bmatrix} = [A_i]^T \begin{Bmatrix} \bar{X}^o_{Dij} \\ \bar{Y}^o_{Dij} \\ \bar{Z}^o_{Dij} \end{Bmatrix} \qquad (72a)$$

and

$$\begin{Bmatrix} L'_{Dij} \\ M'_{Dij} \\ N'_{Dij} \end{Bmatrix} = [A_i]^T \begin{Bmatrix} \bar{L}^o_{Dij} \\ \bar{M}^o_{Dij} \\ \bar{N}^o_{Dij} \end{Bmatrix} \qquad (72b)$$

The loads at mass m_j, in jth body axes, are obtained from equation (70) as

$$\begin{Bmatrix} X'_{Dji} \\ Y'_{Dji} \\ Z'_{Dji} \end{Bmatrix} = -[A_j]^T \begin{Bmatrix} X^o_{Dij} \\ Y^o_{Dij} \\ Z^o_{Dij} \end{Bmatrix} \qquad (73a)$$

and

$$\begin{Bmatrix} L'_{Dji} \\ M'_{Dji} \\ N'_{Dji} \end{Bmatrix} = -[A_j]^T \begin{Bmatrix} L^o_{Dij} \\ M^o_{Dij} \\ N^o_{Dij} \end{Bmatrix} \qquad (73b)$$

The minus sign is necessary because the sense of the loads acting on mass j is opposite the sign convention for the loads acting on mass j, as shown in Figure 6.

We now obtain the total forces and moments acting on mass i by summing the contributions from equations (72) and (73) over the second subscript. This is the same method as employed for the internal forces, equation (35), and explained earlier.

$$X_{Di} = \sum_{j=1}^{N} X'_{Dij} \quad Y_{Di} = \sum_{j=1}^{N} Y'_{Dij} \quad Z_{Di} = \sum_{j=1}^{N} Z'_{Dij}$$

$$L_{Di} = \sum_{j=1}^{N} L'_{Dij} \quad M_{Di} = \sum_{j=1}^{N} M'_{Dij} \quad N_{Di} = \sum_{j=1}^{N} N'_{Dij} \tag{74}$$

These are the total damping forces and moments acting on mass m_i, in ith body axes.

We now digress briefly to discuss the determination of the diagonal damping matrix $\left[C_{ij}\right]$ used in equation (68). The first three diagonal elements of this matrix are given simply by

$$C_{ijk} = 2\overline{C}_{ij}\left[K_{ijkk}(m_i+m_j)\right]^{1/2} \quad k = 1,2,3 \tag{75}$$

where K_{ijkk} is the kth diagonal element of the 6 x 6 stiffness matrix $\left[K_{ij}\right]$ for beam ij. $\overline{C}_{ij}$ is an input constant giving the damping ratio used for beam ij. Equation (75) gives the viscous damping constant corresponding to the input damping $\overline{C}_{ij}$, for the isolated system consisting of masses i and j connected by beam ij. A separate $\overline{C}_{ij}$ is input for each beam ij.

For the rotational degrees of freedom, we must first rotate the inertia matrix for m_j into ith mass axes. This is evidently given by

$$[I_j]_{\substack{i \\ \text{axes}}} = [A_i]^T[A_j][I_j][A_j]^T[A_i] \tag{76}$$

where $\left[I_j\right]$ is the 3 x 3 inertia matrix for mass m_j.

$$[I_j] = \begin{bmatrix} I_{xj} & I_{xyj} & I_{xzj} \\ I_{xyj} & I_{yj} & I_{yzj} \\ I_{xzj} & I_{yzj} & I_{zj} \end{bmatrix} \tag{77}$$

The last three elements of $\lceil C_{ij} \rfloor$ are now given simply by

$$C_{ijk} = 2\bar{C}_{ij}\left[K_{ijkk} I_{ij(k-3)(k-3)}\right]^{1/2} \quad k = 4,5,6 \tag{78}$$

where $I_{ij(k-3)(k-3)}$ are the diagonal elements of the I_{ij} inertia sum matrix defined as

$$[I_{ij}] \triangleq [A_{ij}]^T \Big[[I_i]+[I_j]\Big]_{\substack{i \\ \text{axes}}} [A_{ij}] \tag{79}$$

Note that I_{ij} is just the sum of I_i and I_j, rotated into beam ij axes. This rotation must be performed because K_{ijkk} in equation (78) is associated with beam ij axes. Equations (75) and (78) give the six $\lceil C_{ij} \rfloor$ terms necessary for equation (68). These terms are computed prior to the main time loop in the program, since they involve no time-varying quantities. This completes the discussion of the damping forces and moments.

Total Forces and Moments at m_i (X_i, Y_i, Z_i, L_i, M_i, and N_i)

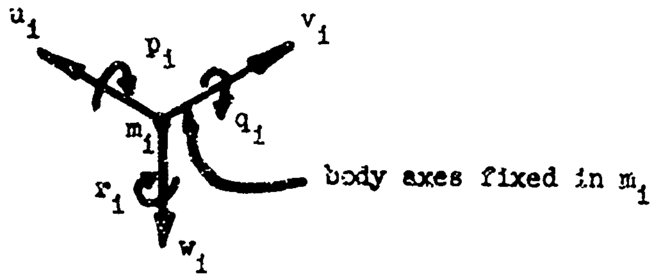
The total forces and moments at m_i, in ith body axes, are used to drive the six rigid-body degrees of freedom of lumped mass m_i. These total forces and moments are just the sum of the components, i.e., the gravity, aerodynamic, internal, crash and damping forces and moments. The total loads are given by

$$\begin{aligned}
X_i &= X_{G_i} + X_{A_i} + X_{I_i} + X_{C_i} + X_{D_i} \\
Y_i &= Y_{G_i} + Y_{A_i} + Y_{I_i} + Y_{C_i} + Y_{D_i} \\
Z_i &= Z_{G_i} + Z_{A_i} + Z_{I_i} + Z_{C_i} + Z_{D_i} \\
L_i &= L_{I_i} + L_{C_i} + L_{D_i} \\
M_i &= M_{I_i} + M_{C_i} + M_{D_i} \\
N_i &= N_{I_i} + N_{C_i} + N_{D_i}
\end{aligned} \tag{80}$$

There are no gravity and aerodynamic moments. The terms of equation (80) come from equations (4), (7), (35), (66), and (74).

Rigid-Body Equations of Motion of Each Mass

Having obtained all the forces and moments acting on each mass m_i, we can now write the rigid-body equations of motion for mass m_i. Euler's equations of motion are used. These are derived in Reference 43; the derivation is not repeated here. The body axis components of the absolute (relative to ground) translational velocity of mass m_i are denoted by u_i, v_i, and w_i. The corresponding rotational velocities are designated p_i, q_i, and r_i. These velocities are shown in the following sketch:



Euler's equations of motion are six equations for the time derivatives of the six velocities, in terms of the six total forces and moments from the preceding section, the velocities themselves, and the inertia properties of mass m_i. These equations are (from Reference 43):

$$
\begin{aligned}
\dot{u}_i &= \frac{X_i g}{W_i} - q_i w_i + r_i v_i \\
\dot{v}_i &= \frac{Y_i g}{W_i} - r_i u_i + p_i w_i \\
\dot{w}_i &= \frac{Z_i g}{W_i} - p_i v_i + q_i u_i \\
\dot{p}_i &= \frac{1}{\Delta_i}\left[\begin{aligned}&\left(L_i-A_i\right)\left(I_{y_i} I_{z_i} - I^2_{yz_i}\right) + \left(M_i-B_i\right)\left(I_{xy_i} I_{z_i} + I_{yz_i} I_{xz_i}\right)\\ &+\left(N_i-C_i\right)\left(I_{xy_i} I_{yz_i} + I_{y_i} I_{xz_i}\right)\end{aligned}\right] \\
\dot{q}_i &= \frac{1}{\Delta_i}\left[\begin{aligned}&\left(L_i-A_i\right)\left(I_{xy_i} I_{z_i} + I_{yz_i} I_{xz_i}\right) + \left(M_i-B_i\right)\left(I_{x_i} I_{z_i} - I^2_{xz_i}\right)\\ &+\left(N_i-C_i\right)\left(I_{x_i} I_{yz_i} + I_{xz_i} I_{xy_i}\right)\end{aligned}\right] \\
\dot{r}_i &= \frac{1}{\Delta_i}\left[\begin{aligned}&\left(L_i-A_i\right)\left(I_{xy_i} I_{yz_i} + I_{y_i} I_{xz_i}\right) + \left(M_i-B_i\right)\left(I_{x_i} I_{yz_i} + I_{xz_i} I_{xy_i}\right)\\ &+\left(N_i-C_i\right)\left(I_{x_i} I_{y_i} - I^2_{xy_i}\right)\end{aligned}\right]
\end{aligned}
\tag{81}
$$

where

$$
\begin{aligned}
\Delta_i &= I_{x_i}\left(I_{y_i} I_{z_i} - I^2_{yz_i}\right) - I_{xy_i}\left(I_{xy_i} I_{z_i} + I_{xz_i} I_{yz_i}\right) - I_{xz_i}\left(I_{xy_i} I_{yz_i} + I_{y_i} I_{xz_i}\right) \\
A_i &= q_i\left(He_{z_i} - I_{xz_i} p_i - I_{yz_i} q_i + I_{z_i} r_i\right) - r_i\left(He_{y_i} - I_{xy_i} p_i + I_{y_i} q_i - I_{yz_i} r_i\right) \qquad (82) \\
B_i &= r_i\left(He_{x_i} + I_{x_i} p_i - I_{xy_i} q_i - I_{xz_i} r_i\right) - p_i\left(He_{z_i} - I_{xz_i} p_i - I_{yz_i} q_i + I_{z_i} r_i\right) \\
C_i &= p_i\left(He_{y_i} - I_{xy_i} p_i + I_{y_i} q_i - I_{yz_i} r_i\right) - q_i\left(He_{x_i} + I_{x_i} p_i - I_{xy_i} q_i - I_{xz_i} r_i\right)
\end{aligned}
$$

X_i, Y_i, Z_i, L_i, M_i, and N_i are the total forces and moments from equation (80). I_{xi}, I_{yi}, and I_{zi} are the moments of inertia of mass m_i about its body fixed axes. I_{xyi}, I_{yzi}, and I_{zxi} are the products of inertia, e.g., $I_{xyi} = \int x_i y_i dm_i$, etc. H_{exi}, H_{eyi}, and H_{ezi} are the angular momenta of masses m_i, due to rotation of internal masses within m_i, such as propellers, rotors, and engine turbines. These terms are used only for a few selected masses, such as the rotor disk, the engine, and the tail boom. They are input constants.

The above equations of motion are integrated numerically to yield u_i, v_i, w_i, and p_i, q_i, r_i. We obtain the translational velocities in ground axes by a simple transformation.

$$
\begin{Bmatrix} \dot{x}_i \\ \dot{y}_i \\ \dot{z}_i \end{Bmatrix} = [A_i] \begin{Bmatrix} u_i \\ v_i \\ w_i \end{Bmatrix} \qquad (83)
$$

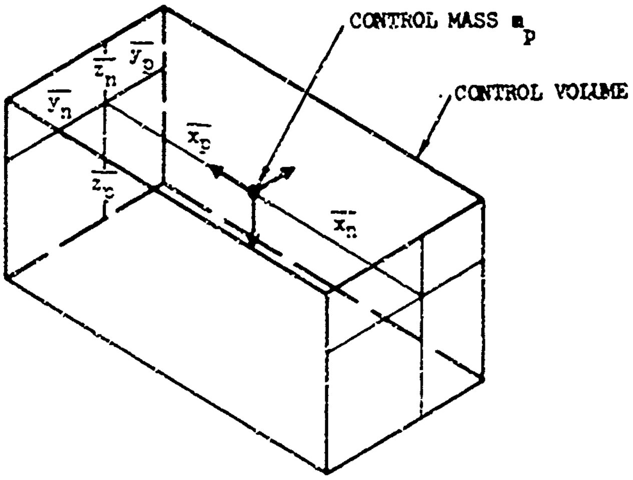
Similarly, the angular velocities p_i, q_i, and r_i are the body axes components of the instantaneous absolute rotation rate $\vec{\omega}_i$ of mass m_i. These variables do not correspond to any set of coordinates which specify the orientation of the airplane. Therefore, in order to solve for the orientation, it is necessary to transform the p', q', r' to the time derivatives $\dot{\phi}_i$, $\dot{\theta}_i$, $\dot{\psi}_i$ of the Euler angles. By summing the orthogonal projections of $\dot{\phi}_i$, $\dot{\theta}_i$, $\dot{\psi}_i$ onto each of the body fixed axes, the following kinematic relations are obtained (Reference 43):

$$\begin{aligned} \dot{\phi}_i &= p_i + (q_i \sin\phi_i + r_i \cos\phi_i) \tan\theta_i \\ \dot{\theta}_i &= q_i \cos\phi_i - r_i \sin\phi_i \\ \dot{\psi}_i &= (q_i \sin\phi_i + r_i \cos\phi_i) \sec\theta_i \end{aligned} \tag{84}$$

Equations (83) and (84) are integrated numerically to obtain x_i, y_i, z_i and ϕ_i, θ_i, ψ_i. Also, p_i, q_i, and r_i are integrated to obtain the quantities inp_i, inq_i, and inr_i. The incremental changes in these integrals are used in equation (23). They represent the incremental rotations of mass m_i in body fixed axes.

Control Volume Mass Penetration Calculations

The computer program includes the calculation of whether or not any of the N lumped masses have penetrated into an input control volume. The purpose of these calculations is to determine if a major mass item (such as the transmission) has moved into a position where it threatens the vehicle's passengers. Therefore, the control volume input is intended to define the volume of the vehicle in which human occupants are present. The rectangular control volume is located with respect to one of the lumped masses, which is specified in the input. The following sketch shows a typical rectangular control volume defined with respect to mass m_p.



The six walls of the control volume are always perpendicular to the three body axes fixed in mass m_p. Thus, the spatial orientation of the control volume varies as mass m_p rotates. $\bar{x}_p$, $\bar{x}_n$, $\bar{y}_p$, $\bar{y}_n$, $\bar{z}_p$, and $\bar{z}_n$, all positive, are the input constants defining the distances from m_p to the six walls, measured in the positive and negative directions along the body fixed axes of m_p.

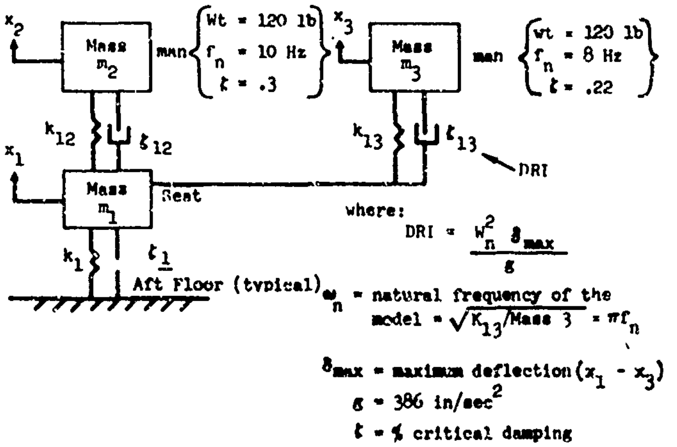
Mass penetration is determined by merely examining the pth body axes components of a vector from control mass m_p to mass m_i, $i = 1,2,\ldots,N$ $(i \neq p)$. These components are given simply by

$$\begin{Bmatrix} x_{p_i} \\ x_{p_i} \\ z_{p_i} \end{Bmatrix} = [A_p]^T \begin{Bmatrix} x_i - x_p \\ y_i - y_p \\ z_i - z_p \end{Bmatrix} \qquad i = 1,2,\ldots,N(i \neq p) \tag{85}$$

where $[A_p]$ is the transformation matrix $[A_i]$ for $i = p$. These vector components are then tested against the control volume dimensions. If all three vector components lie within the corresponding pairs of control volume walls, then the ith point has penetrated inside the control volume. Whenever a mass penetration occurs, the program prints out the time and mass that penetrated. These data are repeated in a summary table at the end of the run, showing all the mass penetrations for that run.

Dynamic Response Index (DRI)

The program also includes the capability of computing Dynamic Response Index (DRI) for certain selected masses. DRI is a nondimensionalized measure of the compression of the human spinal column, and statistical data is available relating DRI to the probability of spinal injury. References 35 and 36 describe DRI's in detail. Basically, all that is involved is the following mathematical model:


x_2
Mass m_2
man $\begin{cases} Wt = 120 \text{ lb} \\ f_n = 10 \text{ Hz} \\ \zeta = .3 \end{cases}$
x_3
Mass m_3
man $\begin{cases} wt = 120 \text{ lb} \\ f_n = 8 \text{ Hz} \\ \zeta = .22 \end{cases}$
k_{12}
ζ_{12}
k_{13}
ζ_{13}
DRI
x_1
Mass m_1
Seat
k_1
ζ_1
Aft Floor (typical)
where:
$DRI = \frac{W_n^2 \delta_{max}}{g}$
ω_n = natural frequency of the model = $\sqrt{K_{13}/\text{Mass } 3} = \pi f_n$
δ_{max} = maximum deflection $(x_1 - x_3)$
$g = 386 \text{ in/sec}^2$
ζ = % critical damping

Mass m_1 is the occupant's seat. Mass m_2 is the upper torso of the occupant; the frequency and damping ratio given are intended to properly model the dynamic response of the upper torso to the seat's excitation. Mass m_3 is also the upper torso, but the stiffness and damping are slightly different. This is done to obtain a response number (DRI) for mass m_3 that correlates well with statistical injury data. The important point is that mass m_3 is driven by mass m_1, but the interconnecting forces only drive mass m_3, not mass m_1. Thus, the coupled systems of m_1 and m_2 determine the response of m_1, and this response drives m_3. The Dynamic Response Index is defined in the previous sketch by

$$DRI = \frac{\omega_n^2 \delta}{g}$$

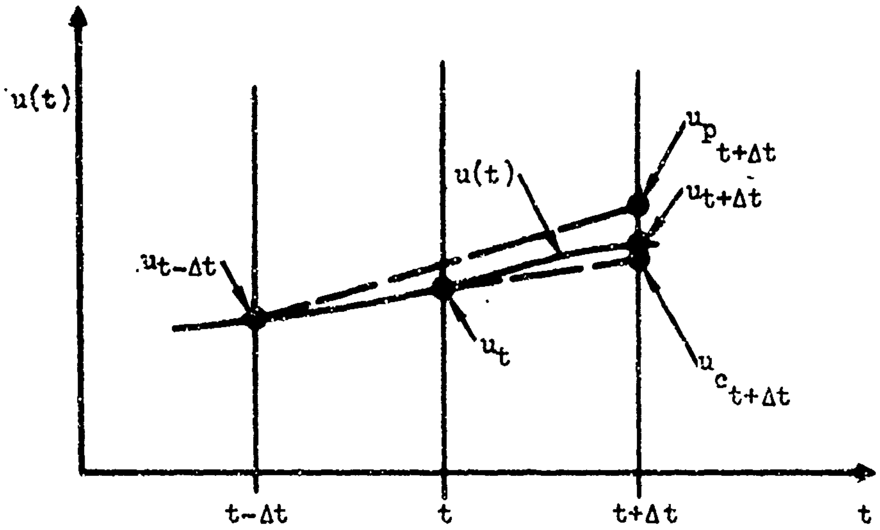
Plugging in the constants, we obtain

$$DRI = 6.55\delta$$

If the damping were zero, the DRI would be the acceleration of mass m_3. With damping, it is a nondimensionalized measure of spring compression. In the computer program, δ is taken as $-vb_1$ (Equation 26) for the ij element corresponding to the beam between mass 1 and 3. The program is coded so that for selected ij pairs (specified by the input), the internal force acts only on mass j, not on mass i. In the above sketch, beam 1-3 would be treated in this way, with its internal forces acting only on mass 3. The only restriction is in the numbering of the masses; the mass representing the torso must be assigned a larger number than the mass representing the seat.

Integration Routine

The equations of motion derived earlier are integrated numerically in the computer program KRASH. The integration scheme employed is a modified predictor-corrector method. The following sketch shows a time history of a typical response quantity, say, u. Assume that u and $\dot{u}$ are



known at time t and all previous times. The predicted value of u at t + Δt, $u_{p_{t+\Delta t}}$ is computed as

$$u_{p_{t+\Delta t}} = u_{t-\Delta t} + 2\Delta t\dot{u}_t \qquad (86)$$

This is shown in the above sketch by the upper dashed line of slope $\dot{u}_t$. Using this predicted value of u at t + Δt, the derivative $\dot{u}$ at t + Δt is computed from the equations derived in the theory. This derivative is then averaged with $\dot{u}$ at t to determine a corrected value of u at t + Δt:

$$u_{c_{t+\Delta t}} = u_t + \frac{\Delta t}{2}(\dot{u}_{t+\Delta t}+\dot{u}_t) \tag{87}$$

This is shown by the lower dashed line in the above sketch. The final value used for $u_{t+\Delta t}$ is a weighted average of the predicted and corrected values. For the present program, the weighting used is 4 to 1 in favor of the corrected value. Hence

$$u_{t+\Delta t} = 0.8u_{c_{t+\Delta t}} + 0.2u_{p_{t+\Delta t}} \tag{88}$$

A computational flow diagram for this scheme is shown in Figure 11. Since the technique is not self-starting (due to the $u_{t-\Delta t}$ term in equation (86)), a simple Euler integration is used for the first step. The subroutine DERIV encompasses all the equations derived in the theory, and is used to compute the derivatives of all the variables, knowing the variables themselves.

The iteration shown by the dashed line in Figure 11 is often employed with this scheme, the iteration continuing until the predicted and corrected values agree to within a specified tolerance. However, the iteration is not used in the program KRASH. Due to the large number of computations in the subroutine DERIV, it is more efficient to go through DERIV only once per time step, and to choose a sufficiently small time step Δt to obtain the desired accuracy.

The subroutine IC computes all the initial values (at t = 0) of the variables necessary for the integration to proceed. The following section discusses the calculations of these initial conditions.

Initial Conditions

Initial values (at t = 0) are required for the following quantities:

$$\left.\begin{array}{ll} x_i,\ y_i,\ z_i & \phi_i,\ \theta_i,\ \psi_i \\ u_i,\ v_i,\ w_i & p_i,\ q_i,\ r_i \\ \dot{x}_i,\ \dot{y}_i,\ \dot{z}_i & \dot{\phi}_i,\ \dot{\theta}_i,\ \dot{\psi}_i \end{array}\right\} \quad i = 1,2,\ldots,N$$

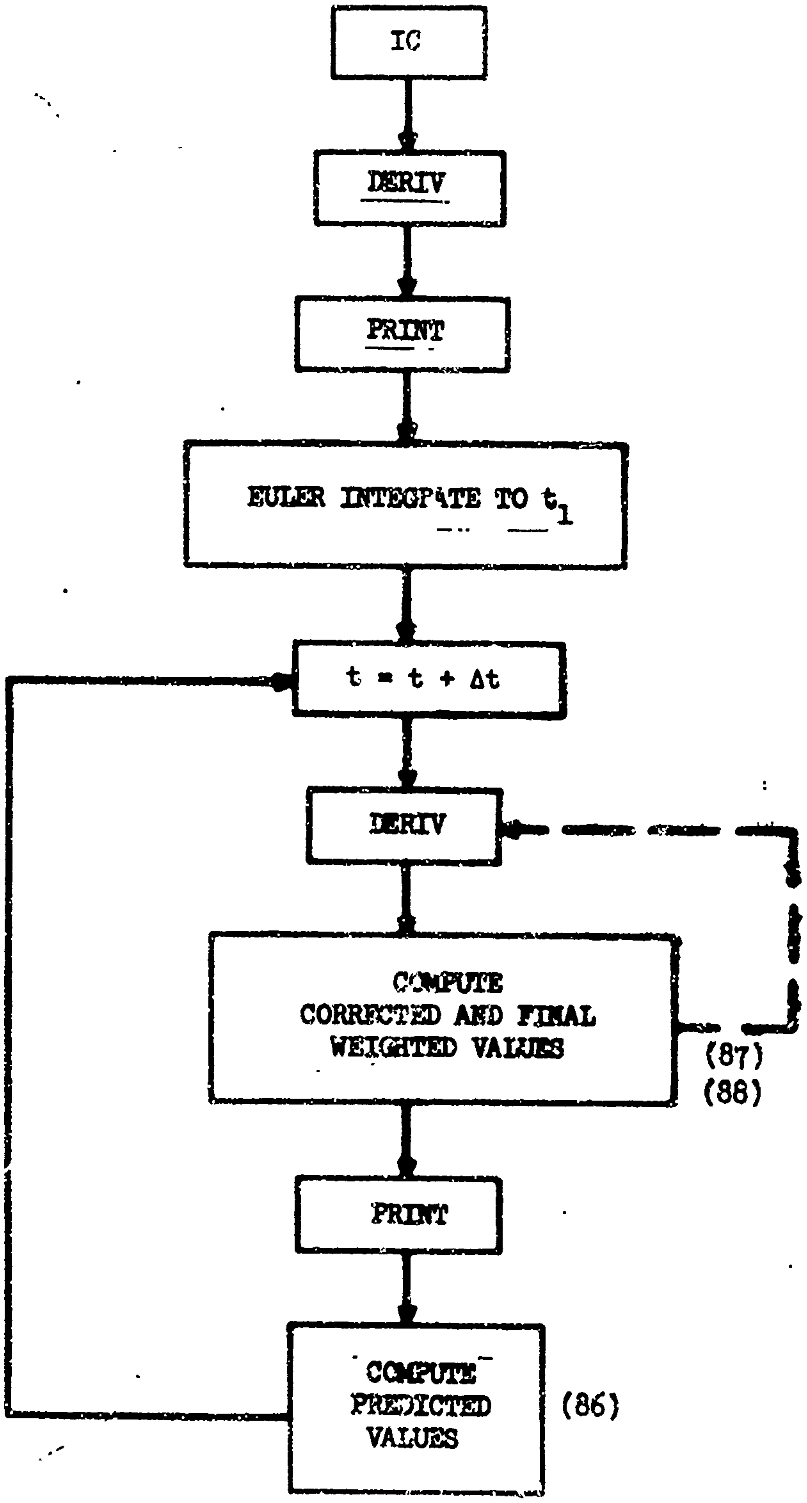

IC
DERIV
PRINT
EULER INTEGRATE TO t_1
t = t + Δt
DERIV
COMPUTE
CORRECTED AND FINAL
WEIGHTED VALUES
(87)
(88)
PRINT
COMPUTE
PREDICTED
VALUES
(86)

Figure 11. Numerical Integration Flow Diagram.

vb_{ijl}	all input ij pairs		$l = 1\text{-}6$
FM_{ijkl}	all input ij pairs	$k = 1\text{-}6$	$l = 1\text{-}6$

$$\left.\begin{array}{l} X'_{ij},\ Y'_{ij},\ldots,\ N'_{ij} \\ X'_{ji},\ Y'_{ji},\ldots,\ N'_{ji} \end{array}\right\} \text{ all input ij pairs}$$

The initial conditions which are input to the program are the following:

$\dot{x}_g,\ \dot{y}_g,\ \dot{z}_g$	vehicle c.g. velocity in ground axes
$p',\ q',\ r'$	vehicle angular velocity in body axes
$\phi',\ \theta',\ \psi'$	vehicle attitude, Euler angles of vehicle relative to ground

First the total vehicle weight is computed from the individual mass weights (input):

$$W_{TOT} = \sum_{i=1}^{N} W_i \tag{89}$$

Next, the location of the overall vehicle c.g., in the $H_{,x'',y'',z''}$ coordinate system, is determined. We have

$$\begin{aligned} x''_G &= \frac{1}{W_{TOT}} \sum_{i=1}^{N} W_i x''_i \\ y''_G &= \frac{1}{W_{TOT}} \sum_{i=1}^{N} W_i y''_i \\ z''_G &= \frac{1}{W_{TOT}} \sum_{i=1}^{N} W_i z''_i \end{aligned} \tag{90}$$

We now write an expression for the ground coordinates of m_i:

$$\begin{Bmatrix} x_i \\ y_i \\ z_i \end{Bmatrix} = \begin{Bmatrix} x_G \\ y_G \\ z_G \end{Bmatrix} + [A'] \begin{Bmatrix} x_i' \\ y_i' \\ z_i' \end{Bmatrix} \tag{91}$$

or

$$va_{ij} = vg_j + \sum_{l=1}^{3} A'_{jl} vip_{il} \qquad j = 1,2,3$$

where x_G, y_G, and z_G are currently unknown, and

$$\begin{Bmatrix} x_i' \\ y_i' \\ z_i' \end{Bmatrix} = - \begin{Bmatrix} x_i'' - x_G'' \\ y_i'' - y_G'' \\ z_i'' - z_G'' \end{Bmatrix} \tag{92}$$

or

$$vip_{ij} = -(vipp_{ij} - gpp_{ij}) \qquad j = 1,2,3$$

The $vipp_{ij}$ are the input coordinates of the m_i, and the $vgpp_{ij}$ were computed in (90), so the vip_{ij} are known. In equation (91), $[A']$ is known from the input Euler angles ϕ', θ', and ψ'. The only unknowns in (91) are x_G, y_G, z_G (defined as vg_j). Clearly, the x and y ground coordinates of the initial c.g. position are arbitrary, so these are set to zero. It remains only to determine the initial c.g. height, z_G (vg_3). This height is either input to the program or, if zero is input, is chosen so that the lowest crash point (C_{xk}, C_{yk}, C_{zk} in Figure 1) is initially 0.001 inch above the ground. From equations (44) and (45), we have the z coordinate of the kth spring for the ith mass as

$$vc_{i3k} = va_{i3} + A_{i3k}\bar{l}_{ik} \tag{93}$$

From equation (91), we know va_{i3} to be

$$va_{i3} = vg_3 + \sum_{l=1}^{3} A'_{3l} vip_{il} \tag{94}$$

once vg_3 (z_G) is known. Combining (93) and (94), we have

$$vc_{i3k} = vg_3 + \sum_{l=1}^{3} A'_{3l} vip_{il} + A_{i3k} \bar{l}_{ik} \tag{95}$$

Now set vg_3 (z_G) = 0, and determine the largest value of vc_{i3k}, varying over i and k to test all crash springs. Denote this largest value by z_{cmax}; this is the vertical location of the lowest spring if z_G were equal to zero. Finally, z_G is determined by

$$z_G = -z_{cmax} - 0.001 \tag{96}$$

This results in the lowest spring being 0.001 inch above the ground. Now we can use (91) to determine the initial x_i, y_i, z_i:

$$\begin{Bmatrix} x_i \\ y_i \\ z_i \end{Bmatrix} = \begin{Bmatrix} 0 \\ 0 \\ -z_{c_{max}} - 0.001 \end{Bmatrix} + [A'] \begin{Bmatrix} x'_i \\ y'_i \\ z'_i \end{Bmatrix} \tag{97}$$

where x'_i, y'_i, z'_i are known from (92). If a nonzero z_G is input, then (95) and (96) are ignored and (91) is used directly instead of (97).

To perform the above calculations, we need to know $[A_i]$, which is used in equation (95). From the definitions of the transformation matrices (refer to Table I earlier), we have simply

$$[A_i] = [A'][A''_i] \qquad i = 1,2,\ldots,N \tag{98}$$

ith body axes to c.g. axes

c.g. axes to ground axes

Equation (98) also allows us to determine the initial values for ϕ_i, θ_i, ψ_i. First θ_i is determined from $A_{i31} = -\sin\theta_i$ as

$$\theta_i = -\sin^{-1} A_{i31} \tag{99}$$

Next ϕ_i is found from $A_{i32} = \sin\phi_i \cos\theta_i$, since θ_i is now known:

$$\phi_i = \sin^{-1}\left(\frac{A_{i32}}{\cos\theta_i}\right) \tag{100}$$

Finally, ψ_i is obtained from $A_{i21} = \cos\theta_i \sin\psi_i$:

$$\psi_i = \sin^{-1}\left(\frac{A_{i21}}{\cos\theta_i}\right) \tag{101}$$

Note that equations (99), (100) and (101) all involve arc sine, so the difference between a positive and negative angle can be detected.

Next the linear and angular velocities are calculated. Differentiating equation (91), we obtain

$$\begin{Bmatrix} \dot{x}_i \\ \dot{y}_i \\ \dot{z}_i \end{Bmatrix} = \begin{Bmatrix} \dot{x}_G \\ \dot{y}_G \\ \dot{z}_G \end{Bmatrix} + [\dot{A}'] \begin{Bmatrix} x'_i \\ y'_i \\ z'_i \end{Bmatrix} \tag{102}$$

where the first vector is input and the second vector is given by (92). $[\dot{A}']$ is treated the same as $[\dot{A}_i]$ was earlier in the theory:

$$[\dot{A}'] = [A'][D'] \tag{103}$$

where

$$[D'] = \left[\begin{array}{c|c|c} 0 & \dot{\theta}'\sin\phi' - \dot{\psi}'\cos\phi'\cos\theta' & \dot{\theta}'\cos\phi' + \dot{\psi}'\sin\phi'\cos\theta' \\ -\dot{\theta}'\sin\phi' + \dot{\psi}'\cos\phi'\cos\theta' & 0 & -\dot{\phi}' + \dot{\psi}'\sin\theta' \\ -\dot{\theta}'\cos\phi' - \dot{\psi}'\sin\phi'\cos\theta' & \dot{\phi}' - \dot{\psi}'\sin\theta' & 0 \end{array}\right] \tag{104}$$

ϕ', θ', and ψ' are input, and $\dot{\phi}'$, $\dot{\theta}'$, and $\dot{\psi}'$ are calculated from the input p', q', and r' by (refer to equation (84)):

$$\begin{Bmatrix} \dot{\phi}' \\ \dot{\theta}' \\ \dot{\psi}' \end{Bmatrix} = [\bar{A}'] \begin{Bmatrix} p' \\ q' \\ r' \end{Bmatrix} \tag{105}$$

where

$$[\bar{A}'] = \begin{bmatrix} 1 & \sin\phi'\tan\theta' & \cos\phi'\tan\theta' \\ 0 & \cos\phi' & -\sin\phi' \\ 0 & \sin\phi'\sec\theta' & \cos\phi'\sec\theta' \end{bmatrix} \tag{106}$$

Once $\dot{x}_i$, $\dot{y}_i$, and $\dot{z}_i$ are known from (102), these are simply transformed into body axes to obtain u_i, v_i, and w_i:

$$\begin{Bmatrix} u \\ v_i \\ w_i \end{Bmatrix} = [A_i]^T \begin{Bmatrix} \dot{x}_i \\ \dot{y}_i \\ \dot{z}_i \end{Bmatrix} \tag{107}$$

The angular velocities in body axes (p_i, q_i, and r_i) are equal to the vehicle angular velocity (p', q', and r'), transformed from c.g. axes to ith mass axes:

$$\begin{Bmatrix} p_i \\ q_i \\ r_i \end{Bmatrix} = [A_i'']^T \begin{Bmatrix} p' \\ q' \\ r' \end{Bmatrix} \qquad (108)$$

Next we determine $\dot{\phi}_i$, $\dot{\theta}_i$, and $\dot{\psi}_i$ by equations analagous to (105) and (106), only using angles ϕ_i and θ_i this time:

$$\begin{Bmatrix} \dot{\phi}_i \\ \dot{\theta}_i \\ \dot{\psi}_i \end{Bmatrix} = [\bar{A}_i] \begin{Bmatrix} p_i \\ q_i \\ r_i \end{Bmatrix} \qquad (109)$$

where

$$[\bar{A}_i] = \begin{bmatrix} 1 & \sin\phi_i \tan\theta_i & \cos\phi_i \tan\theta_i \\ 0 & \cos\phi_i & -\sin\phi_i \\ 0 & \sin\phi_i \sec\theta_i & \cos\phi_i \sec\theta_i \end{bmatrix} \qquad (110)$$

The only remaining initial conditions to be determined are the beam deflections and forces vb_{ijl}, FM_{ijkl} and $X'_{ij},\ldots,N'_{ij}$. At present, the program is written so that the initial values for all these quantities are zero. This is only true for the case where there are no aerodynamic loads, so that all masses are uniformly accelerating downward at 1g. Therefore, if aerodynamic loads are used in the program, the initial conditions will not be correct since internal forces would be required to balance the aerodynamic and gravity forces. However, this is not considered a serious limitation since the vast majority of accident cases involve loss of aerodynamic lift.

Also computed in the initial condition subroutine, although not truly initial conditions, are the Euler angles θ''_{ij} and ψ''_{ij}. These angles are used in $[A_{ij}]$, which transforms vectors from beam ij axes to ith body axes. This computation is performed only if the input angles ϕ''_i, θ''_i, and ψ''_i are all zero. This means that all the ith body axes are parallel to the vehicle c.g. axes. This is normally the case, since the inertia properties for the masses are usually available in these axes. Figure 11 shows beam ij connecting points m_i and m_j. The distances from m_i to m_j, measured along vehicle c.g. (') axes, are given by

$$\begin{Bmatrix} x'_{ij} \\ y'_{ij} \\ z'_{ij} \end{Bmatrix} = \begin{Bmatrix} x'_j - x'_i \\ y'_j - y'_i \\ z'_j - z'_i \end{Bmatrix} \tag{111}$$

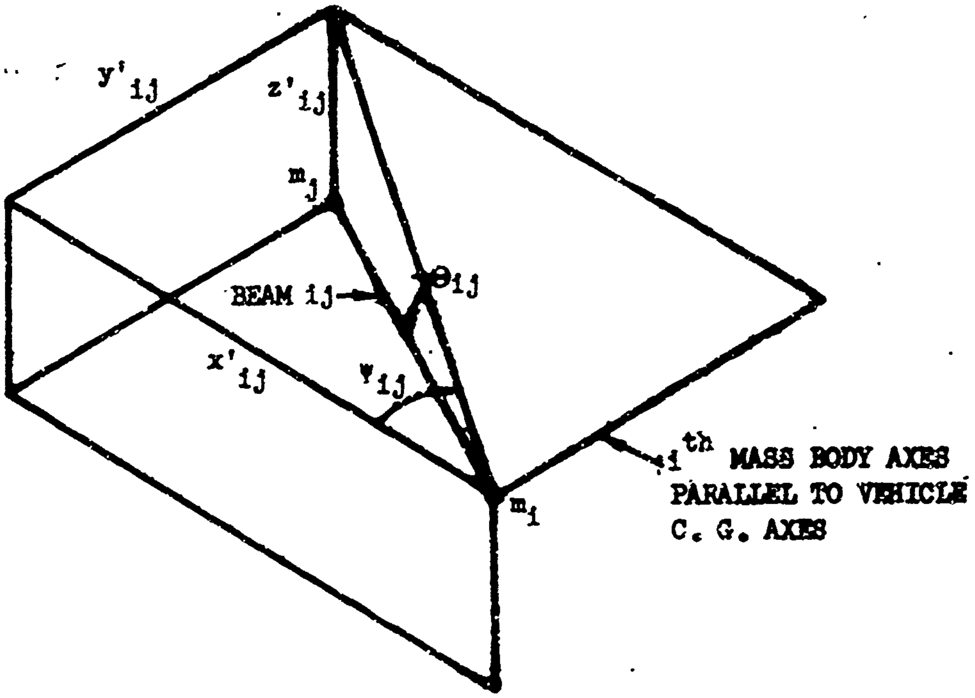
where the terms on the right-hand side are computed in equation (92). Figure 12 shows the Euler angles ψ_{ij} and θ_{ij}. The basic equations for these can be seen from Figure 12 to be

$$\begin{aligned} \psi_{ij} &= \tan^{-1} \frac{y'_{ij}}{x'_{ij}} \\ \theta_{ij} &= \tan^{-1} \frac{z'_{ij}}{\left({x'_{ij}}^2 + {y'_{ij}}^2 \right)^{1/2}} \end{aligned} \tag{112}$$

However, due to the problems encountered in calculating these angles in various quadrants, as well as in calculating 90° angles, the algorithm shown in Figure 13 is actually used to compute these angles. The arc tangent functions used give angles between +180° and -180°.

The function also automatically gives $\psi_{ij} = \text{SIGN}\ (y'_{ij}) \times \frac{\pi}{2}$ if $x'_{ij} = 0$ in the right-hand equation for ψ_{ij}. The test for $y'_{ij} = 0$ is necessary to avoid the indeterminate 0/0 for ψ_{ij} if both y'_{ij} and x'_{ij} are zero.

The remaining Euler angle ϕ_{ij} is always input, since it is not a function of the locations of m_i and m_j. This "roll" angle is chosen so that the resultant beam ij axes coincide with convenient structural axes. ϕ_{ij} is usually zero. This completes the computation of the initial conditions.



y'_{ij}
z'_{ij}
m_j
θ_{ij}
BEAM ij
x'_{ij}
ψ_{ij}
m_i
i^{th} MASS BODY AXES PARALLEL TO VEHICLE C. G. AXES

Figure 12. Euler Angles θ_{ij} and ψ_{ij}.

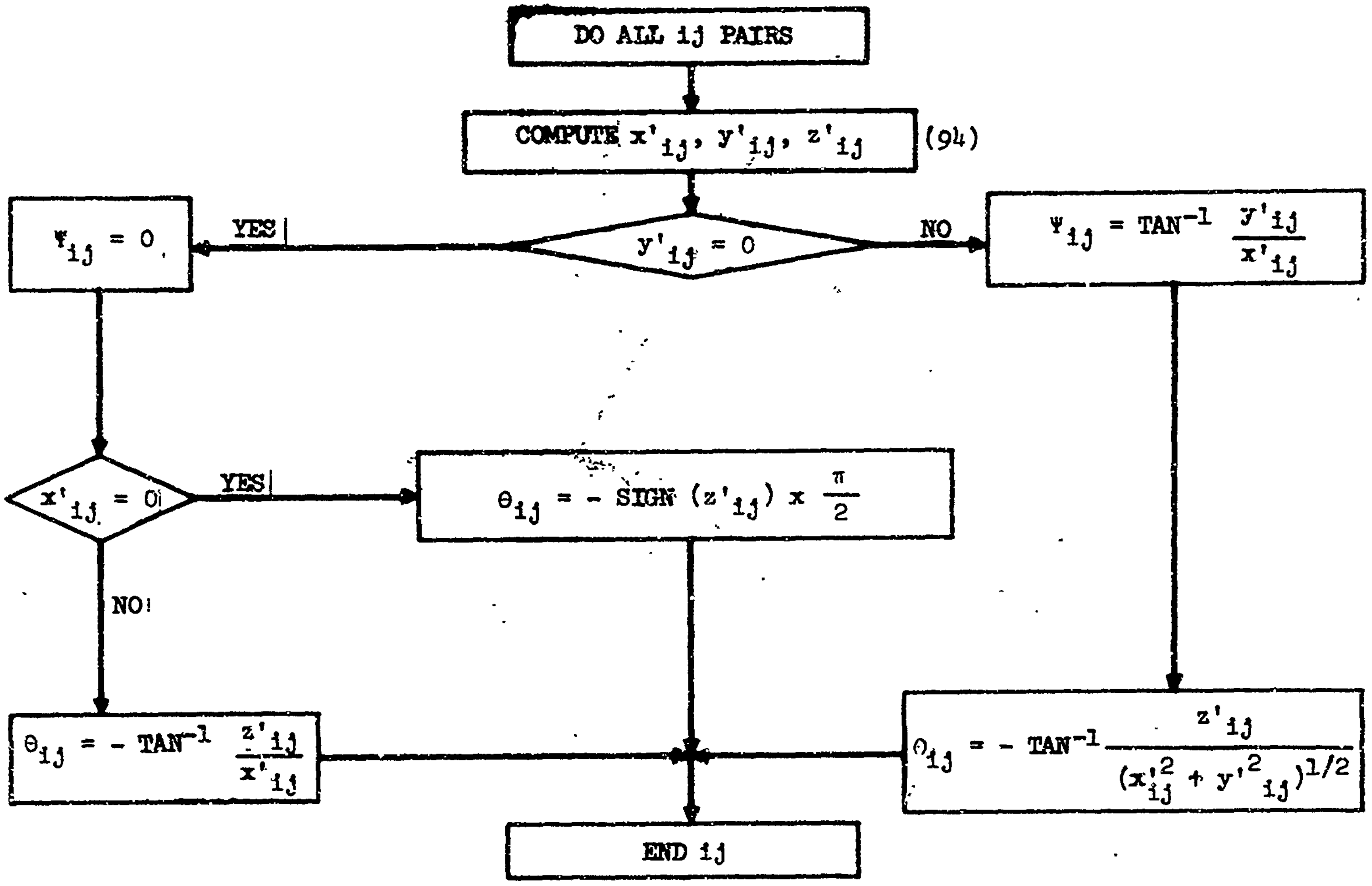

DO ALL ij PAIRS
COMPUTE x'_{ij}, y'_{ij}, z'_{ij}
(94)
$y'_{ij} = 0$
YES
NO
$\Psi_{ij} = 0$
$\Psi_{ij} = \mathrm{TAN}^{-1} \frac{y'_{ij}}{x'_{ij}}$
$x'_{ij} = 0$
YES
NO
$\Theta_{ij} = - \mathrm{SIGN}\ (z'_{ij}) \times \frac{\pi}{2}$
$\Theta_{ij} = - \mathrm{TAN}^{-1} \frac{z'_{ij}}{x'_{ij}}$
$\Theta_{ij} = - \mathrm{TAN}^{-1} \frac{z'_{ij}}{(x'^{2}_{ij} + y'^{2}_{ij})^{1/2}}$
END ij

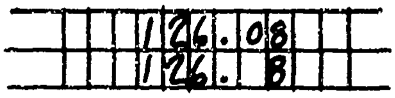
Figure 13. Computation of Θ_{ij} and ψ_{ij}.

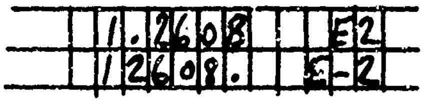
USER'S GUIDE

This section describes all the input necessary to run the program, and the output available from the program.

Input

The input data format is described in detail in this section and is shown in Figure 14. Unless otherwise specified, all quantities are input in inch, pound, second, and radian units. For cards 0300 and on, the input format is 6E12.0 unless otherwise noted. Each card has 6 fields; each field is 12 columns wide. As an example of this format, the number 126.08 can be input in the following ways:





Blank columns are treated as zeros. When the E format is used, the exponent must be right justified in the field. On cards 0100 thru 0299, the format I3 is sometimes used. This simply requires a right justified integer in a field width of 3. Sequence numbers in columns 77 thru 80 should be used corresponding to those shown in the input format to facilitate deck assembly and changes. All tabular input is linearly interpolated between input values and extrapolated beyond the two end values, if necessary.

Card 0100 - This card contains the title for the case being analyzed. All text material on card 0100 is reproduced at the top of every page of the output and on every plot.

Card 0101 - N is the total number of lumped masses. ΔPrint/Δt is the integer multiple of Δt at which output is printed. i is the number of points in the KR_{ijl} vs v_{ijl} tables. i currently must be 6. Δt is the numerical integration time interval. t_{max} is the time span being analyzed.

Cards 0200 thru 02XX - These cards contain the Euler angles ϕ_{ij}, θ_{ij}, and ψ_{ij} for all beams ij. The beam interconnections are defined by the i's and j's input. i must be less than j, but there is no other requirement on the ordering of the ij pairs. ϕ_{ij} is always input; θ_{ij} and ψ_{ij} need not be input if ϕ_i'', θ_i'', and ψ_i'' on cards 0500-05XX are all zero. In the latter case, θ_{ij} and ψ_{ij} are computed in initial conditions. ϕ_{ij} will normally be zero. There must be a blank card following all the ij pairs input.

Cards 0300 thru 030X - As many of these cards as necessary are used to input the weights (not masses) of the N lumped masses.

Cards 0310 thru 03XX - N of these cards are required. Each card inputs the six moments and products of inertia for the ith mass, i = 1, 2, ..., N.

Cards 0400 thru 04XX - He_{xi}, He_{yi}, and He_{zi} are the body axes components of the angular moments of masses m_i, due to rotation of internal masses within m_i. These are normally zero.

Cards 0450 thru 045X - l_{ci} are the aerodynamic lift constants used in equation (5).

Cards 0460 thru 0462 - The cards contain the overall vehicle initial conditions. x_G, y_G, and z_G are the ground axes components of the initial c.g. velocity. p', q', and r' are the c.g. coordinate system components of the initial angular velocity of the vehicle. p' is the roll velocity, q' the pitch velocity, and r' the yaw velocity. ϕ', θ', and ψ' are the Euler angles relating the initial position of the vehicle to ground coordinates. ϕ' is the roll angle, θ' the pitch angle, and ψ' the yaw angle. z_G is the negative of the initial vehicle c.g. height above ground. If this is input as zero (blank), the initial condition subroutine computes a value of z_G so that the lowest extremity of the vehicle is .1 inch above the ground.

Cards 0470 thru 04XX - These cards are used to input the coordinates of the N lumped masses. x''_i is the Fuselage Station (increasing aft), y''_i is the Butt Line (positive left), and z''_i is the Water Line (increasing upward).

Cards 0500 thru 05XX - ϕ''_i, θ''_i, ψ''_i, i = 1,2,...,N are the Euler angles from the c.g. axes to the ith mass axes. If the ith mass body-fixed areas are parallel to the vehicle c.g. coordinate axes, which is usually the case, these are all input as zero. Note that if any nonzero values are input, then θ_{ij} and ψ_{ij} on cards 0200 thru 02XX must be input.

Cards 0600 thru 06XX - $\bar{l}_{ik}$, i = 1,2,...,N; k = 1,2,3 are the free lengths of the external springs. Zeros are input if no spring is utilized. $\bar{l}_{ik}$ is positive if it radiates out from mass m_i in the positive direction of the ith mass body axes; $\bar{l}_{ik}$ is negative if it radiates in the opposite direction. Springs in both directions are not allowed.

Cards 0700 thru 07XX - Integer format I3 is used to define the SP_{ik}. If $SP_{ik} = 1$, there is a kth spring on the ith mass; if $SP_{ik} = 0$, there is no spring.

Cards 0710 thru 07XX - mu_{ik} are the friction coefficients between ground and the end of the ik spring.

Cards 0750 thru 07XX - ke_{ik} are the linear unloading stiffnesses and also bottoming stiffnesses for the ik spring.

Cards 0800 thru 0805 - These six cards are used to input the 6 x 6 linear stiffness matrix $[K_{ij}]$ for the first ij beam, listed on card 0200. Each card inputs one row of the matrix.

Cards 0806 thru 1999 - As many cards as necessary are used to input all the remaining 6 x 6 $[K_{ij}]$ matrices. These matrices must be ordered the same as the ij pairs are ordered on cards 0200 thru 02XX.

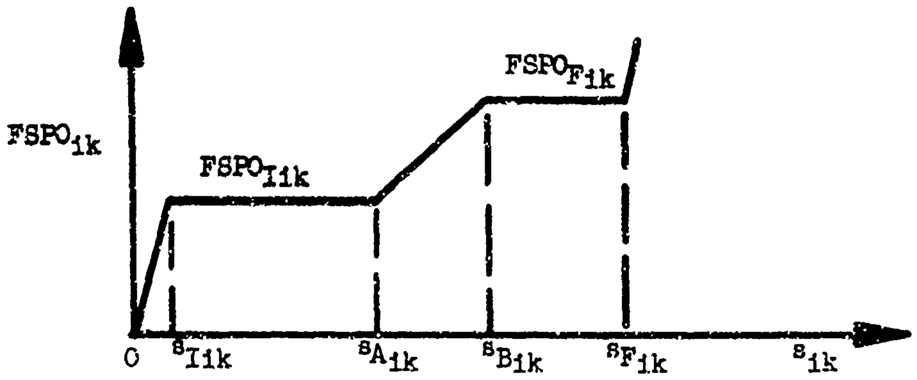
Cards 2000 thru 20XX - $v_{max\ ijk}$, k = 1-6 are the maximum beam deflections and rotations for beam ij. These are ordered the same as cards 0200 thru 02XX. When any one of the six maximum deflections or rotations is exceeded (either positive or negative), element ij fractures and its internal forces are set to zero for the remainder of the run. The deflections and rotations are of point j with respect to point i, in beam ij axes. They are ordered x, y, z, ϕ, θ, ψ.

Cards 2100 thru 21XX - DX_{ijl} are the spacings for the six equally spaced abscissa values in the following table of KR_{ijl} vs vb_{ijl}, for l = 1 thru 6.

Cards 2100 thru 2206 - Each card inputs the six KR_{ijl} values defining the table of KR_{ijl} vs vb_{ijl}, for the first ij pair. The first value corresponds to $vb_{ijl} = 0$, the remaining five are spaced DX_{ijl}, to the right. Six cards are input, one for each l deflection or rotation, ordered x, y, z, ϕ, θ, ψ. KR_{ijl} are the diagonal elements of a 6 x 6 diagonal stiffness reduction matrix. It is initially 1.0, corresponding to a linear system, and then increases or decreases with vb_{ijl}, depending on whether the nonlinear beam gets stiffer or softer. Refer to the THEORY section on internal forces for the usage of KR_{ijl}.

Cards 2207 thru 2XXX - As many cards as necessary are used to input the KR_{ijl} tables for the remaining ij pairs. Six cards per ij pair are used. The ij pairs are ordered as on cards 0200 thru 02XX.

Cards 3000 thru 30XX - These cards are used to input tables of $FSPO_{ik}$ vs s_{ik}, the axial load in the external springs versus the spring compression. The program is currently written so that a table of the following form must be input:



This table is defined by six parameters S_{Iik}, S_{Aik}, S_{Bik}, S_{Fik}, $FSPO_{Iik}$ and $FSPO_{Fik}$. These parameters are input in order for k = 1, 2, 3 and i = 1,2,..., N. Zeros are input if no spring exists ($SP_{ik} = 0$).

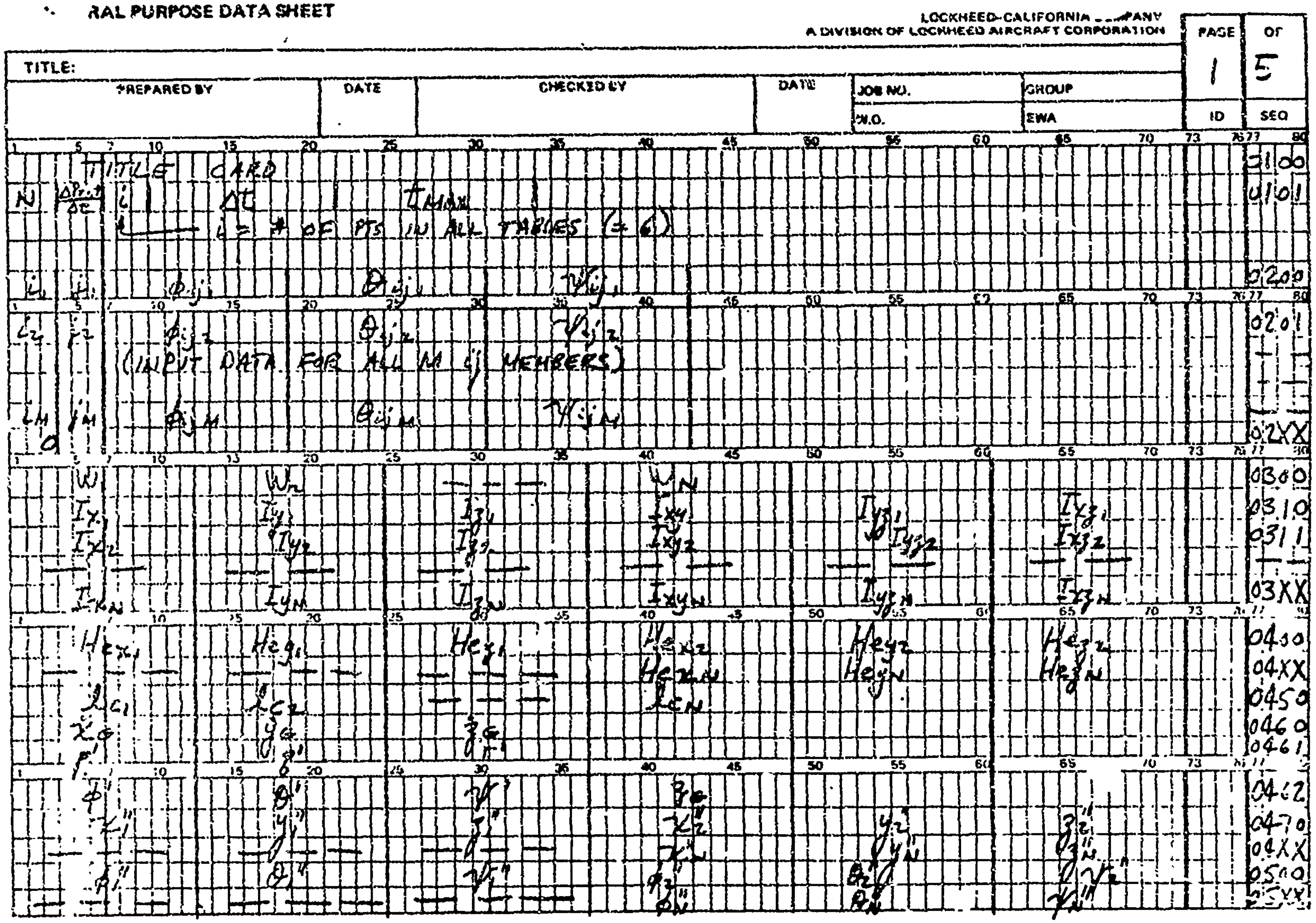
Cards 3200 thru 32XX - These cards are used to input the $\bar{C}_{ij}$ for all the ij pairs defined on cards 0200 thru 02XX. $\bar{C}_{ij}$ is the damping ratio (damping/critical damping) for the isolated system consisting of masses m_i and m_j connected by beam ij. Values of $\bar{C}_{ij}$ between .01 and .05 are generally representative of the structural damping.

Cards 5001 thru 5024 - These cards are used to specify the time history output plots desired. The only input for these cards is either a 1 or a blank. A 1 results in the output of a time history plot for the response quantity indicated; a blank results in no plot for that item. For example, a 1 in the 13th column of card 5003 specifies that a time history plot of z_{13} is to be generated. For cards 5001 thru 5012, the column number in which the 1 is input indicates which mass i is desired. For cards 5013 thru 5024, the column number in which the 1 is input indicates which ij pair is desired, where the ij pairs are ordered as on cards 0200 thru 02XX.

Plots are available for the displacements, velocities and accelerations of all the lumped masses, all the external spring compressions S_{ik}, and all the beam ij total deflections/rotations (vb_{ij}) and forces/moments (F_{ij}). The latter two items are in beam ij axes. Also available are plots of the DRI (Dynamic Response Index). These are identified by the DRI ij element, as described on card 7000 below. The plot variables are labelled automatically, and the plot scales are chosen automatically. The user merely has to specify which plots are desired. Up to 150 plots can be requested per run. Thirty thousand data points are stored for plotting, with the plot time interval depending on run time and number of plots requested. Thus, if the maximum of 150 plots are requested, 200 points will be saved to generate each plot. If the maximum run time is .2 second, this will give one data point every .001 second. For the types of problems analyzed, this appears to be a marginally acceptable resolution. Requesting fewer plots automatically increases the number of points per plot and, hence, the resolution.

Card 6000 - P is the mass to be used to locate the mass penetration control volume. The format is I2. If no mass penetration calculations are required, this card is input blank and card 6001 is not required.

Card 6001 - $\bar{x}n$, $\bar{x}p$, $\bar{y}n$, $\bar{y}p$, $\bar{z}n$, and $\bar{z}p$ are the six distances (all positive), measured from the control mass P to the six sides of the control volume. These are measured along the positive (p) and negative (n) body-fixed axes for mass mp.



RAL PURPOSE DATA SHEET

LOCKHEED-CALIFORNIA ...PANY
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PAGE 1 OF 5

TITLE:

PREPARED BY	DATE	CHECKED BY	DATE	JOB NO.	GROUP	ID	SEQ
				W.O.	EWA		

TITLE CARD — 0100

N $\frac{\Delta P_{r,t}}{\Delta t}$ l Δt t_{max} — 0101

l = # OF PTS IN ALL TABLES (≤ 6)

i_1 j_1 ϕ_{ij_1} θ_{ij_1} ψ_{ij_1} — 0200

i_2 j_2 ϕ_{ij_2} θ_{ij_2} ψ_{ij_2} — 0201

(INPUT DATA FOR ALL M ij MEMBERS)

i_M j_M ϕ_{ij_M} θ_{ij_M} ψ_{ij_M} — 02XX

W_1 W_2 — — — W_N — 0300

I_{x_1} I_{y_1} I_{z_1} I_{xy_1} I_{yz_1} I_{xz_1} — 0310

I_{x_2} I_{y_2} I_{z_2} I_{xy_2} I_{yz_2} I_{xz_2} — 0311

I_{x_N} I_{y_N} I_{z_N} I_{xy_N} I_{yz_N} I_{xz_N} — 03XX

He_{x_1} He_{y_1} He_{z_1} He_{x_2} He_{y_2} He_{z_2} — 0400

He_{x_N} He_{y_N} He_{z_N} — 04XX

l_{c_1} l_{c_2} — — — l_{c_N} — 0450

x_G y_G z_G — 0460

x_G' y_G' z_G' — 0461

ϕ' θ' ψ' — 0462

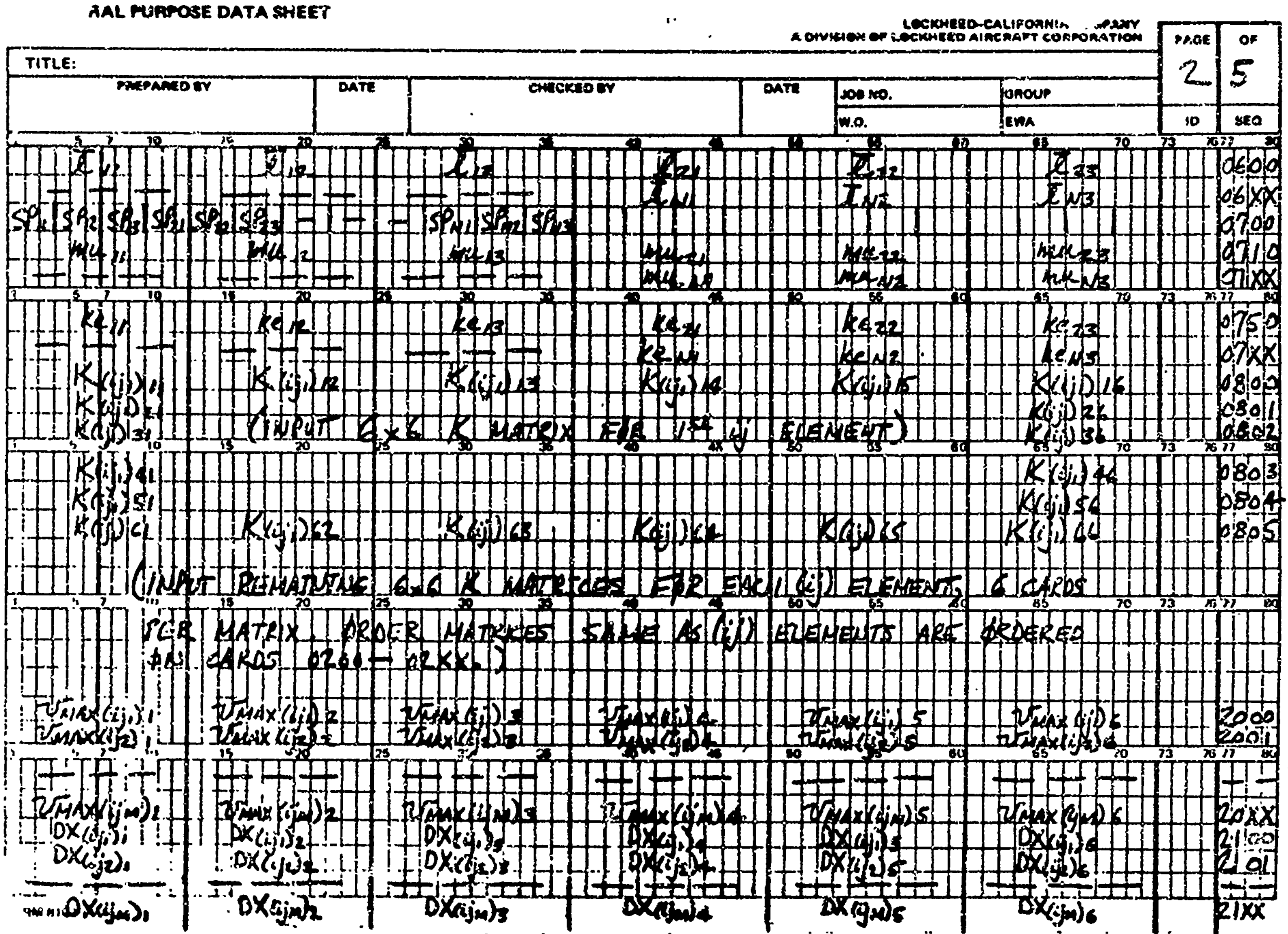
x_1'' y_1'' z_1'' x_2'' y_2'' z_2'' — 0470

x_N'' y_N'' z_N'' — 04XX

ϕ_1'' θ_1'' ψ_1'' ϕ_2'' θ_2'' ψ_2'' — 0500

ϕ_N'' θ_N'' ψ_N'' — 05XX

Figure 14. Input Data Format.



AL PURPOSE DATA SHEET

LOCKHEED-CALIFORNIA PANY
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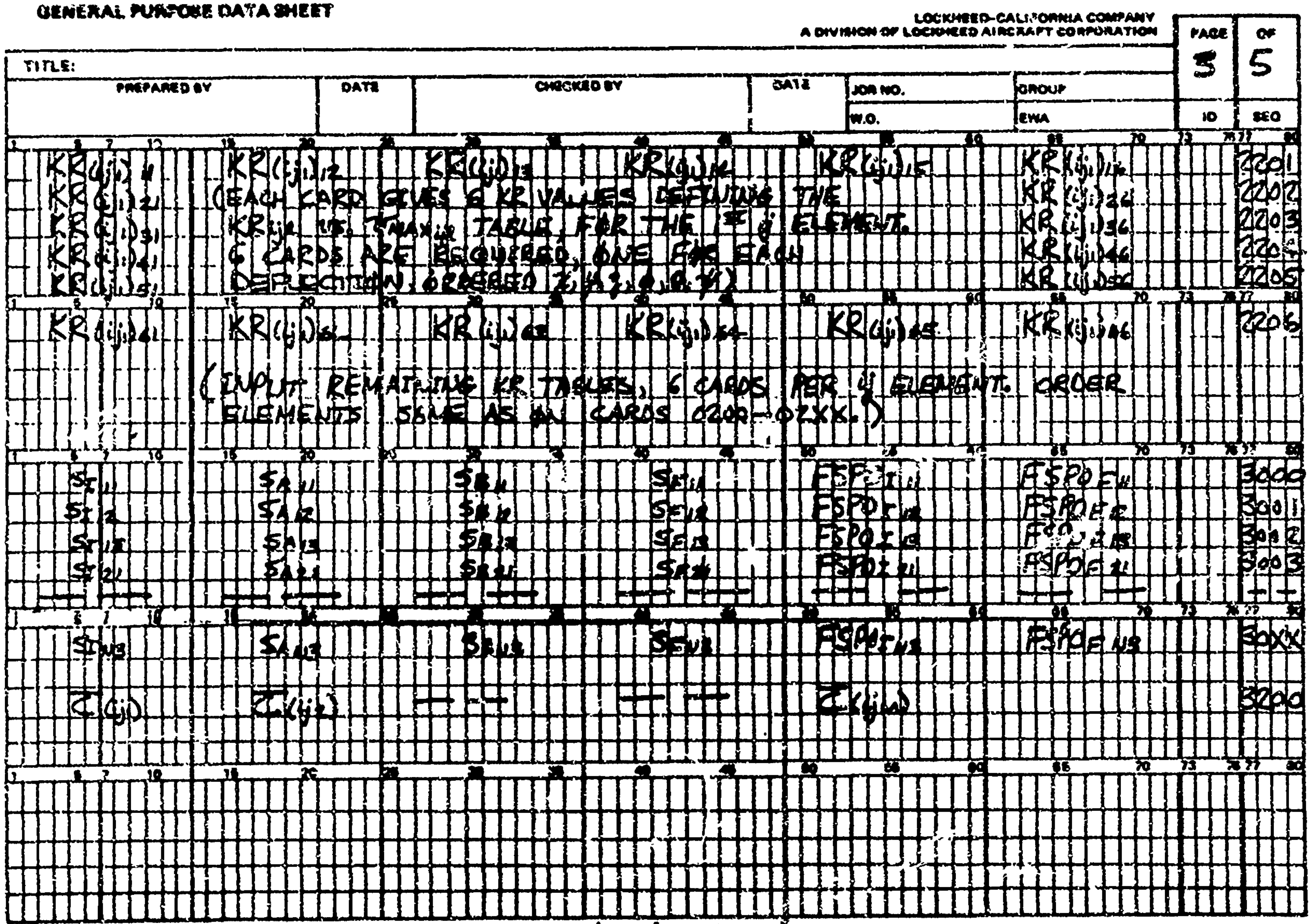
PAGE 2 OF 5

TITLE:

PREPARED BY | DATE | CHECKED BY | DATE | JOB NO. | GROUP
W.O. | EWA | ID | SEQ

ℓ_{11}	ℓ_{12}	ℓ_{13}	ℓ_{21}	ℓ_{22}	ℓ_{23}	0600
—	—	—	ℓ_{N1}	ℓ_{N2}	ℓ_{N3}	06XX
SP_{11} SP_{12} SP_{13}	SP_{21} SP_{22} SP_{23}	— — —	SP_{N1} SP_{N2} SP_{N3}			0700
WL_{11}	WL_{12}	WL_{13}	WL_{21}	WL_{22}	WL_{23}	0710
—	—	—	WL_{N1}	WL_{N2}	WL_{N3}	07XX
KE_{11}	KE_{12}	KE_{13}	KE_{21}	KE_{22}	KE_{23}	0750
—	—	—	KE_{N1}	KE_{N2}	KE_{N3}	07XX
$K(ij)_{11}$	$K(ij)_{12}$	$K(ij)_{13}$	$K(ij)_{14}$	$K(ij)_{15}$	$K(ij)_{16}$	0800
$K(ij)_{21}$					$K(ij)_{26}$	0801
$K(ij)_{31}$	(INPUT 6×6 K MATRIX FOR 1st ij ELEMENT)				$K(ij)_{36}$	0802
$K(ij)_{41}$					$K(ij)_{46}$	0803
$K(ij)_{51}$					$K(ij)_{56}$	0804
$K(ij)_{61}$	$K(ij)_{62}$	$K(ij)_{63}$	$K(ij)_{64}$	$K(ij)_{65}$	$K(ij)_{66}$	0805
(INPUT REMAINING 6×6 K MATRICES FOR EACH (ij) ELEMENT, 6 CARDS PER MATRIX. ORDER MATRICES SAME AS (ij) ELEMENTS ARE ORDERED ON CARDS 0200 → 02XX.)						
$V_{MAX}(ij_1)_1$	$V_{MAX}(ij_1)_2$	$V_{MAX}(ij_1)_3$	$V_{MAX}(ij_1)_4$	$V_{MAX}(ij_1)_5$	$V_{MAX}(ij_1)_6$	2000
$V_{MAX}(ij_2)_1$	$V_{MAX}(ij_2)_2$	$V_{MAX}(ij_2)_3$	$V_{MAX}(ij_2)_4$	$V_{MAX}(ij_2)_5$	$V_{MAX}(ij_2)_6$	2001
—	—	—	—	—	—	—
$V_{MAX}(ij_m)_1$	$V_{MAX}(ij_m)_2$	$V_{MAX}(ij_m)_3$	$V_{MAX}(ij_m)_4$	$V_{MAX}(ij_m)_5$	$V_{MAX}(ij_m)_6$	20XX
$DX(ij_1)_1$	$DX(ij_1)_2$	$DX(ij_1)_3$	$DX(ij_1)_4$	$DX(ij_1)_5$	$DX(ij_1)_6$	2100
$DX(ij_2)_1$	$DX(ij_2)_2$	$DX(ij_2)_3$	$DX(ij_2)_4$	$DX(ij_2)_5$	$DX(ij_2)_6$	2101
—	—	—	—	—	—	—
$DX(ij_m)_1$	$DX(ij_m)_2$	$DX(ij_m)_3$	$DX(ij_m)_4$	$DX(ij_m)_5$	$DX(ij_m)_6$	21XX

Figure 14. (Continued)



GENERAL PURPOSE DATA SHEET

LOCKHEED-CALIFORNIA COMPANY
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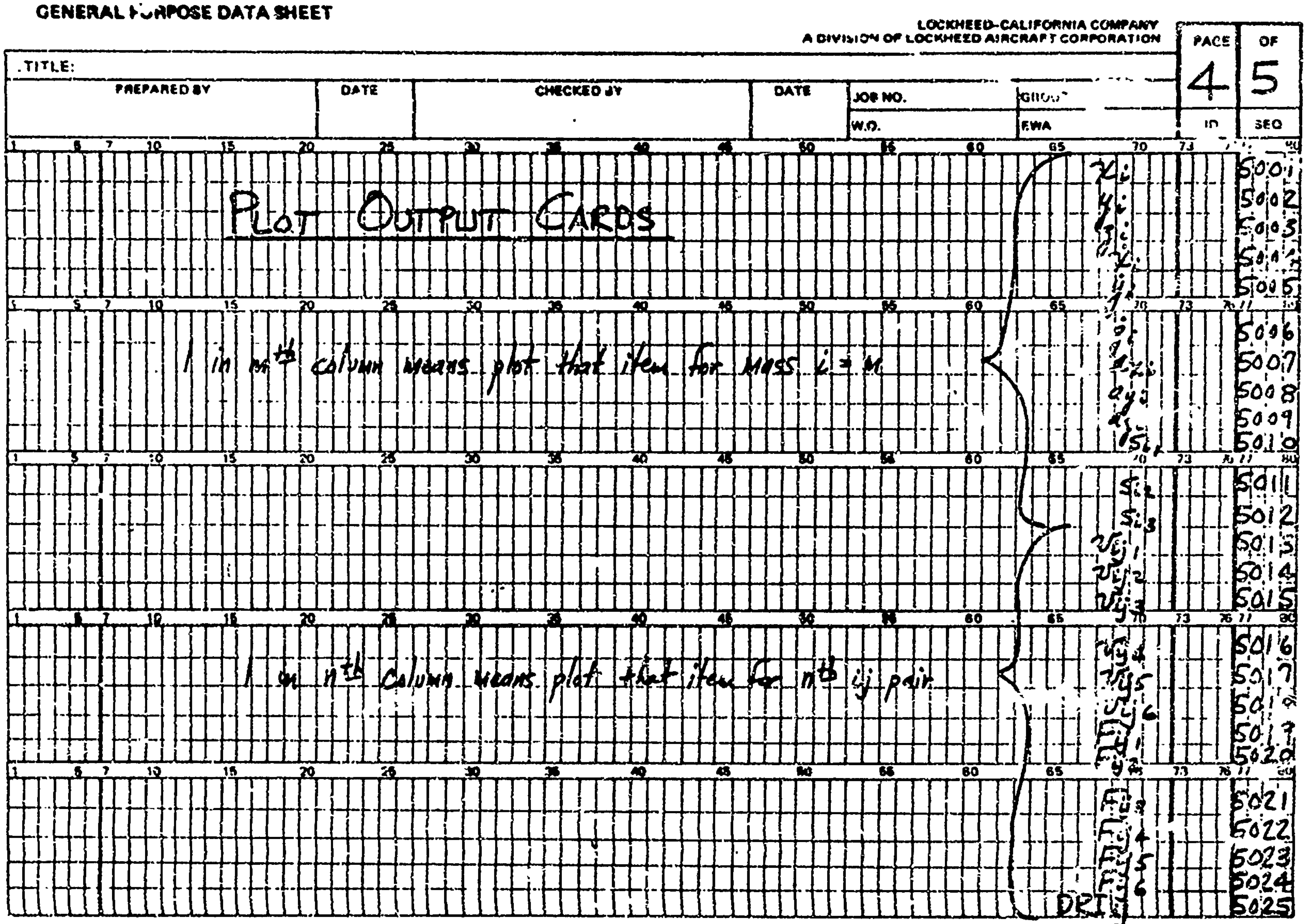
TITLE:					PAGE 3	OF 5
PREPARED BY	DATE	CHECKED BY	DATE	JOB NO. / W.O.	GROUP / EWA	ID / SEQ

$KR(i,j)_{11}$	$KR(i,j)_{12}$	$KR(i,j)_{13}$	$KR(i,j)_{14}$	$KR(i,j)_{15}$	$KR(i,j)_{16}$	2201
$KR(i,j)_{21}$	(EACH CARD GIVES 6 KR VALUES DEFINING THE				$KR(i,j)_{26}$	2202
$KR(i,j)_{31}$	KR_{ij} VS. τMAX_{ij} TABLE FOR THE ij ELEMENT.				$KR(i,j)_{36}$	2203
$KR(i,j)_{41}$	6 CARDS ARE REQUIRED, ONE FOR EACH				$KR(i,j)_{46}$	2204
$KR(i,j)_{51}$	DEFLECTION, ORDERED $Z(i,j,1...6)$)				$KR(i,j)_{56}$	2205
$KR(i,j)_{61}$	$KR(i,j)_{62}$	$KR(i,j)_{63}$	$KR(i,j)_{64}$	$KR(i,j)_{65}$	$KR(i,j)_{66}$	2206
	(INPUT REMAINING KR TABLES, 6 CARDS PER ij ELEMENT. ORDER ELEMENTS SAME AS IN CARDS 0200-02XX.)					
ST_{11}	SA_{11}	SB_{11}	SE_{11}	$FSPOI_{11}$	$FSPOE_{11}$	3000
ST_{12}	SA_{12}	SB_{12}	SE_{12}	$FSPOI_{12}$	$FSPOE_{12}$	3001
ST_{13}	SA_{13}	SB_{13}	SE_{13}	$FSPOI_{13}$	$FSPOE_{13}$	3002
ST_{21}	SA_{21}	SB_{21}	SE_{21}	$FSPOI_{21}$	$FSPOE_{21}$	3003
— —	— —	— —	— —	— —	— —	— —
ST_{NS}	SA_{NS}	SB_{NS}	SE_{NS}	$FSPOI_{NS}$	$FSPOE_{NS}$	30XX
$Z(i,j1)$	$Z(i,j2)$	— —	— —	$Z(i,j,n)$		3200

Figure 14. (Continued)



GENERAL PURPOSE DATA SHEET

LOCKHEED-CALIFORNIA COMPANY
A DIVISION OF LOCKHEED AIRCRAFT CORPORATION

TITLE:					PAGE 4	OF 5
PREPARED BY	DATE	CHECKED BY	DATE	JOB NO.	GROUP	
				W.O.	FWA	ID	SEQ

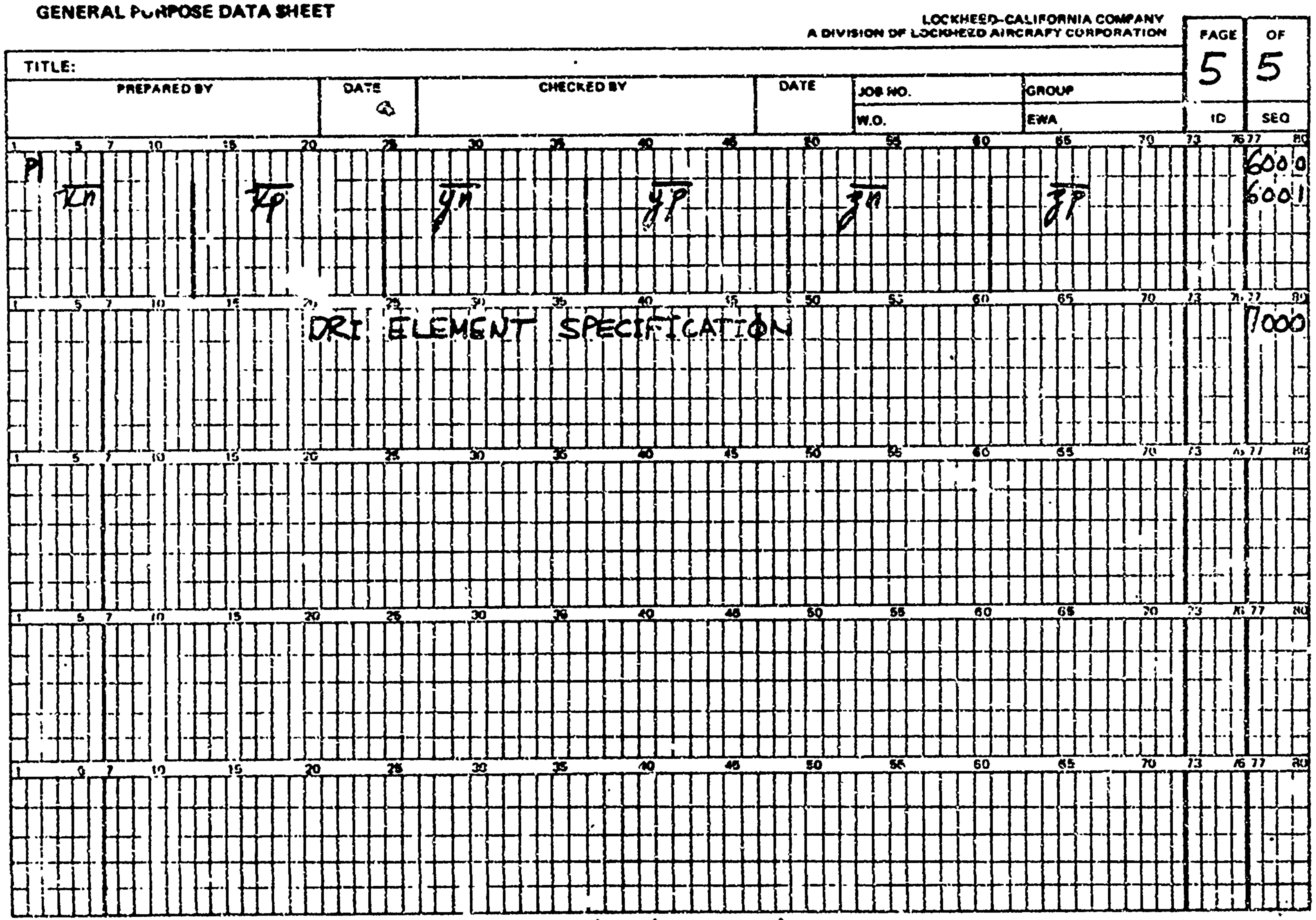
PLOT OUTPUT CARDS

1 in n^{th} column means plot that item for mass $i = n$

1 in n^{th} column means plot that item for n^{th} ij pair

x_i	5001
y_i	5002
z_i	5003
$\dot{x}_i$	5004
$\dot{y}_i$	5005
$\dot{z}_i$	5006
ax_i	5007
ay_i	5008
az_i	5009
S_{i1}	5010
S_{i2}	5011
S_{i3}	5012
v_{ij1}	5013
v_{ij2}	5014
v_{ij3}	5015
v_{ij4}	5016
v_{ij5}	5017
v_{ij6}	5018
F_{ij1}	5019
F_{ij2}	5020
F_{ij3}	5021
F_{ij4}	5022
F_{ij5}	5023
F_{ij6}	5024
DRI_{ij}	5025

Figure 14. (Continued)



GENERAL PURPOSE DATA SHEET

LOCKHEED-CALIFORNIA COMPANY
A DIVISION OF LOCKHEED AIRCRAFT CORPORATION

PAGE	5
OF	5

TITLE:

PREPARED BY

DATE

CHECKED BY

DATE

JOB NO.

W.O.

GROUP

EWA

ID

SEQ

P1 6000

$\overline{x}_n$ $\overline{x}_p$ $\overline{y}_n$ $\overline{y}_p$ $\overline{z}_n$ $\overline{z}_p$ 6001

DRI ELEMENT SPECIFICATION 7000

Figure 14. (Continued)

Print Output

First, all the input data is printed out, with self-explanatory identifying titles. Next, at each print time (= $\Delta\text{Print}/\Delta t \times \Delta t$), the data shown in Figure 15 is printed out. At the top of each page, the case identification data is printed out (from input card 0100). Then the current value of time t is printed.

Next, for each of the N masses, five lines of data are output. x_i, y_i, and z_i are the ground coordinates of m_i. $\dot{x}_i$, $\dot{y}_i$, and $\dot{z}_i$ are the ground axes components of the velocity of m_i. u_i, v_i, and w_i are the ith body axes components of the velocity of m_i. $\dot{u}_i$, $\dot{v}_i$, and $\dot{w}_i$ are the time derivatives of u_i, v_i, and w_i. (These are not equal to the acceleration of m_i, as can be seen from equation (81).) XACCEL, YACCEL, ZACCEL are the body axes components of the acceleration of m_i.

ϕ_i, θ_i, and ψ_i are the Euler angles defining the attitude of body m_i, in roll, pitch and yaw. $\dot{\phi}_i$, $\dot{\theta}_i$, and $\dot{\psi}_i$ are the time derivatives of ϕ_i, θ, and ψ_i. p_i, q_i, and r_i are the body axes components of the angular velocity of m_i; they are the velocities in roll, pitch, and yaw, respectively. $\dot{p}_i$, $\dot{q}_i$, and $\dot{r}_i$ are the body axes components of the angular acceleration of m_i.

Following that output, the running time sums of the internal forces $\{F_{ij}\}$ (Equation (27)) are printed out; the six forces and moments for each ij pair are printed on a line preceded by the identifying i and j. Next, the running time sums of the beam deflections $\{\nu b_{ij}\}$ (Equation (26)) are printed out in the same format.

Finally, the external spring compressions s_{ik} (Equation (47)) are printed out. Each line starts with the i, followed by the s_{ik} for k = 1, 2, 3. Only values of i for which a spring is input are shown.

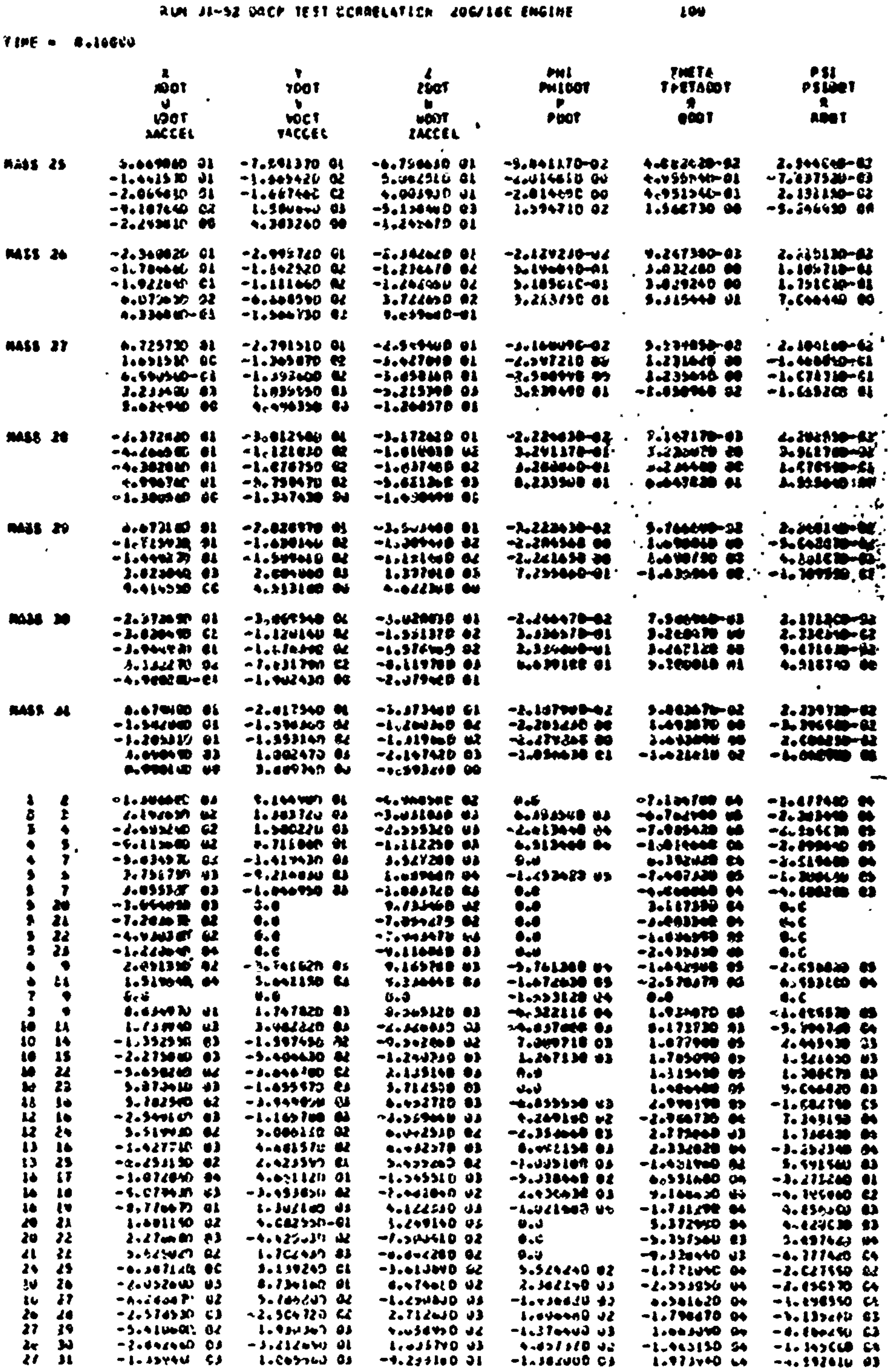
During the course of the run, if any ruptures or control volume mass penetrations occur, the appropriate information is printed out. When a rupture occurs, the word RUPTURE is printed, followed by four items:

1. The ij pair that ruptured, where the numbering corresponds to the ordering of the ij pairs as input on cards 0200 thru 02XX.

2. The l (from 1 to 6) indicating in which direction (in beam axes) the rupture occurred. These are ordered x, y, z, ϕ, θ, and ψ. See Figure 24 for the directions of the beam axes.

3. The νb_{ijl} at the time of rupture. This is the total deflection, in beam axes, in the direction that ruptured.

4. The $\nu_{\max_{ijl}}$ which defines the maximum allowable beam deflection in the lth direction. This is an input constant.



```
RUN JI-52 DRCP TEST CORRELATION 206/18C ENGINE          100

TIME =  0.10000

                X          Y          Z          PHI         THETA        PSI
              XDOT       YDOT       ZDOT       PHIDOT       THETADOT     PSIDOT
                U          V          W            P            Q           R
              UDOT       VDOT       WDOT         PDOT         QDOT        RDOT
             XACCEL     YACCEL     ZACCEL
```

Figure 15. Output Data Format.

```
IG(IJ),JG(IJ),VEEZ(1,IJ),VEEZ(2,IJ),VEEZ(3,IJ),VEEZ(4,IJ),VEEZ(5,IJ),VEEZ(6,IJ)
  1   2     -1.06420D-02   -4.95968D-01    1.44373D 00    3.05261D-02   -4.19620D-02   -1.36573D-02
  2   3      3.57830D-03   -3.01657D-01    1.31795D 00    2.57623D-03   -1.99906D-02   -5.49355D-03
  3   4     -8.07063D-04   -3.00602D-02    3.32332D-02   -7.16253D-04   -5.79936D-03   -2.40812D-03
  4   5     -4.33869D-04   -4.64256D-02    2.58633D-02    7.95336D-07   -1.09646D-03   -1.70241D-03
  4   7     -1.03267D-02   -1.69995D-01    5.48752D-02   -2.86261D-04   -9.29916D-04   -2.19520D-03
  5   6      8.75967D-03   -4.33216D-02    4.87480D-02   -1.40435D-05   -4.15380D-03   -3.45243D-03
  5   7     -3.14921D-02   -1.50463D-01   -2.13531D-02    7.03141D-04    1.75031D-04   -2.33621D-05
  5  20     -1.93376D-02   -9.33063D 00    1.62713D-02   -6.57025D-02    4.77673D-03   -7.33150D-02
  5  21     -4.50220D-03    3.92834D 00    1.26203D-03    7.61649D-02   -4.99965D-04    6.27540D-02
  5  22     -2.80773D-03   -1.68957D-01   -1.98423D-01   -9.05033D-02    2.65414D-03    2.40334D-02
  5  23     -6.95127D-02   -9.50443D-01   -1.60273D-01    7.39423D-02    9.12077D-04   -4.01212D-02
  6   9      2.74785D-05   -1.47587D-01    3.22337D-01   -2.22054D-03   -1.34665D-02   -4.25181D-03
  6  11      3.12449D-03    1.13423D-02    3.62882D-02   -2.02326D-03   -4.32396D-03    1.21220D-03
  7   9      3.42960D-01   -5.66238D-02   -3.09806D-02   -7.56649D-03   -2.76965D-02    1.34636D-03
  8   9     -1.12314D 00   -1.43724D-01    4.79253D-01   -3.68845D-02   -1.17505D-03   -6.55822D-03
 10  11      5.17663D-03    2.60631D-04   -6.34133D-02   -2.04299D-03    4.63785D-02   -7.19924D-04
 10  14     -2.62979D-03   -1.26352D-01   -1.51041D 01    1.25047D-06    3.50040D-01   -2.71632D-03
 10  15     -4.74635D-03   -7.32524D-01   -1.51320D 01    2.23460D-05    3.63901D-01   -2.16131D-02
 10  22     -6.35064D-03   -5.49524D-02   -4.49765D-02   -8.06179D-02    2.86745D-03   -1.71517D-03
 10  23      6.60415D-02   -2.41960D-01    3.11065D-02    7.01038D-02    5.43545D-04   -7.46524D-03
 11  16      3.39246D-03   -1.50257D-02   -1.94115D-02   -9.12975D-03    3.29203D-02   -3.12585D-04
 12  16     -3.43376D-03    3.95547D-02   -1.42016D 00    4.30311D-04    9.52478D-02    2.17211D-03
 12  24      3.72716D-03    7.27430D-01    2.69359D-02   -7.69217D-03   -7.56027D-04    2.23140D-02
 13  16     -6.02984D-04   -1.53090D-02    1.00454D 00    7.95797D-03   -3.38318D-02   -1.62164D-03
 13  25     -4.22225D-03    1.41024D-01    2.93271D-02   -3.37170D-03   -8.30767D-04    5.05726D-03
 16  17     -4.47250D-02    1.20996D-01   -1.91359D 01   -1.71151D-05    3.56200D-01    3.83540D-03
 16  18     -3.78783D-02   -1.06616D 03   -1.51035D 01    8.23115D-05    3.81097D-01   -3.30654D-02
 16  19     -4.26873D-04    6.50832D-04    2.03927D-01   -9.53859D-03   -6.50071D-03    2.07721D-05
 20  21      3.76220D-03    1.11176D-01    3.53477D-02   -1.06315D-02   -2.22365D-04    2.46724D-03
 20  22      3.07367D-02    5.86191D-02   -1.83960D-01    9.25252D-03    4.72799D-03    2.30211D-03
 22  23      7.32418D-03   -9.49277D-03   -1.32763D-01    3.13467D-03    4.61391D-03   -1.17075D-03
 24  25     -7.16963D-04    2.62155D-02   -8.63960D-03    8.93540D-03   -7.12204D-03    5.21401D-04
 10  26     -2.05260D-01   -1.29521D-03    1.13391D-02    2.38234D-03   -2.66994D-03   -2.64952D-03
 16  27     -2.09625D-02    3.53249D-03   -1.92621D-02   -1.43062D-03    6.75624D-03   -1.65124D-03
 26  28     -2.09607D 00   -3.45276D-03    2.92171D-02    1.60660D-04   -2.09104D-03   -9.48052D-04
 27  29     -4.40264D-01    1.06609D-02    3.02612D-03   -1.37604D-03    1.63363D-03   -7.62630D-04
 26  30     -3.61636D 00   -1.48104D-03    1.76600D-02    4.65737D-04   -1.66240D-03   -1.15585D-03
 27  31     -1.74233D 00    1.62945D-02   -2.93214D-03   -1.38209D-03    2.00326D-03   -3.26215D-04
I,SC(I,1),SC(I,2),SC(I,3)
     10     0.0            0.0            2.95260D 00
     11     0.0            0.0            2.63350D 00
     12     0.0            0.0            2.32660D-03
     13     0.0            0.0            3.72557D 00
     14     0.0            0.0            1.85012D-03
     15     0.0            0.0            2.56071D-03
     16     0.0            0.0            1.64106D 00
     17     0.0            0.0            6.07841D-04
     18     0.0            0.0            1.02911D-01
     22     0.0            0.0            2.34200D 00
     23     0.0            0.0            3.61265D 00


MASS        DPI
 30         2.34672D 01
 31         1.14122D 01


RUPTURE SUMMARY

  I          J        TIME

 10         15    0.00786
 16         17    0.08624
 10         14    0.15590
 16         18    0.16338
```

Figure 15. (Continued)

If a control volume mass penetration occurs, the mass which penetrates and the time are printed out. At the end of the run, the ruptures and mass penetrations that occurred during the run are summarized in tables for ready reference.

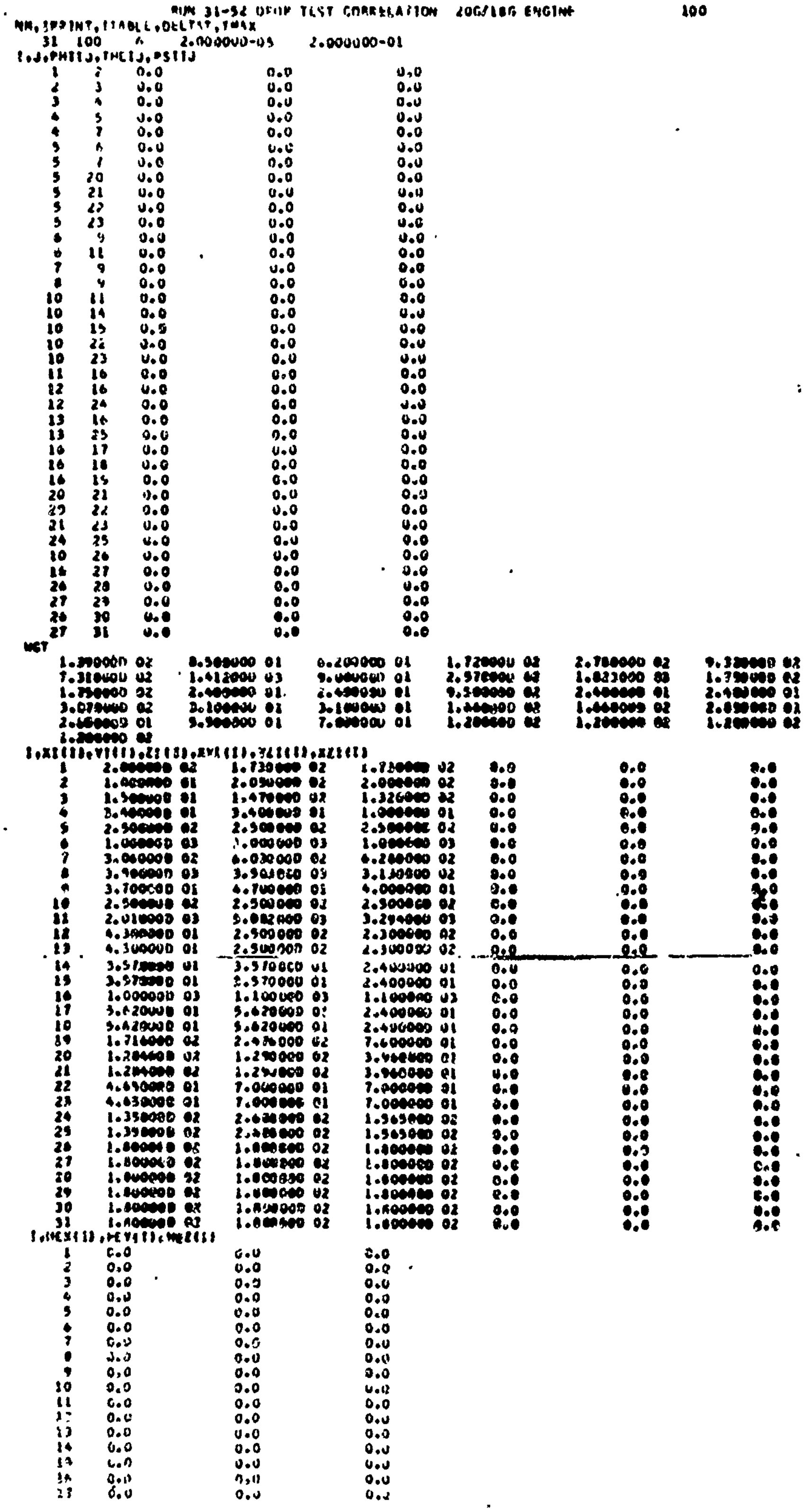
Sample Case

A sample 31 mass case is presented. Figure 16 represents the input data and follows the User's Guide input format (Figure 14). The representative output for one time period is shown in Figure 15 and follows the format described under the User's Guide output format.

Sample output plots are presented in Figures 17, 18, and 19 for the engine vertical velocity, vertical acceleration and vertical mount deflection respectively.

Program Listing

A complete listing of the computer program KRASH, including subroutines, is presented in Figure 20.



```
                    RUN 31-52 DFOP TEST CORRELATION  20G/18G ENGINE            100
NN,JPRINT,ITABLE,DELTST,TMAX
  31  100    6    2.000000-05     2.000000-01
I,J,PHIIJ,THEIJ,PSIIJ
   1   2   0.0              0.0              0.0
   2   3   0.0              0.0              0.0
   3   4   0.0              0.0              0.0
   4   5   0.0              0.0              0.0
   4   7   0.0              0.0              0.0
   5   6   0.0              0.0              0.0
   5   7   0.0              0.0              0.0
   5  20   0.0              0.0              0.0
   5  21   0.0              0.0              0.0
   5  22   0.0              0.0              0.0
   5  23   0.0              0.0              0.0
   6   9   0.0              0.0              0.0
   6  11   0.0              0.0              0.0
   7   9   0.0              0.0              0.0
   8   9   0.0              0.0              0.0
  10  11   0.0              0.0              0.0
  10  14   0.0              0.0              0.0
  10  15   0.5              0.0              0.0
  10  22   0.0              0.0              0.0
  10  23   0.0              0.0              0.0
  11  16   0.0              0.0              0.0
  12  16   0.0              0.0              0.0
  12  24   0.0              0.0              0.0
  13  16   0.0              0.0              0.0
  13  25   0.0              0.0              0.0
  16  17   0.0              0.0              0.0
  16  18   0.0              0.0              0.0
  16  19   0.0              0.0              0.0
  20  21   0.0              0.0              0.0
  20  22   0.0              0.0              0.0
  21  23   0.0              0.0              0.0
  24  25   0.0              0.0              0.0
  10  26   0.0              0.0              0.0
  16  27   0.0              0.0              0.0
  26  28   0.0              0.0              0.0
  27  29   0.0              0.0              0.0
  26  30   0.0              0.0              0.0
  27  31   0.0              0.0              0.0
WGT
    1.390000 02    8.500000 01    6.200000 01    1.720000 02    2.780000 02    9.320000 02
    7.310000 02    1.412000 03    9.000000 01    2.570000 02    1.823000 03    1.790000 02
    1.750000 02    2.400000 01    2.490000 01    9.500000 02    2.400000 01    2.400000 01
    3.079000 02    3.100000 01    3.100000 01    1.440000 02    1.440000 02    2.850000 01
    2.460000 01    5.900000 01    7.000000 01    1.200000 02    1.200000 02    1.200000 02
    1.200000 02
I,XI(I),YI(I),ZI(I),XYI(I),YZI(I),XZI(I)
   1    2.000000 02    1.730000 02    1.720000 02    0.0         0.0         0.0
   2    1.000000 01    2.050000 02    2.000000 02    0.0         0.0         0.0
   3    1.500000 01    1.470000 02    1.326000 02    0.0         0.0         0.0
   4    3.400000 01    3.400000 01    1.000000 01    0.0         0.0         0.0
   5    2.500000 02    2.500000 02    2.500000 02    0.0         0.0         0.0
   6    1.000000 03    1.000000 03    1.000000 03    0.0         0.0         0.0
   7    3.060000 02    6.030000 02    6.280000 02    0.0         0.0         0.0
   8    3.900000 03    3.903060 03    3.130000 02    0.0         0.0         0.0
   9    3.700000 01    4.700000 01    4.000000 01    0.0         0.0         0.0
  10    2.500000 02    2.500000 02    2.500000 02    0.0         0.0         0.0
  11    2.010000 03    5.082000 03    3.294000 03    0.0         0.0         0.0
  12    4.300000 01    2.500000 02    2.300000 02    0.0         0.0         0.0
  13    4.300000 01    2.500000 02    2.300000 02    0.0         0.0         0.0
  14    3.570000 01    3.570000 01    2.400000 01    0.0         0.0         0.0
  15    3.570000 01    3.570000 01    2.400000 01    0.0         0.0         0.0
  16    1.000000 03    1.100000 03    1.100000 03    0.0         0.0         0.0
  17    5.620000 01    5.620000 01    2.400000 01    0.0         0.0         0.0
  18    5.620000 01    5.620000 01    2.400000 01    0.0         0.0         0.0
  19    1.716000 02    2.476000 02    7.600000 01    0.0         0.0         0.0
  20    1.284000 02    1.290000 02    3.960000 01    0.0         0.0         0.0
  21    1.284000 02    1.290000 02    3.960000 01    0.0         0.0         0.0
  22    4.650000 01    7.000000 01    7.000000 01    0.0         0.0         0.0
  23    4.650000 01    7.000000 01    7.000000 01    0.0         0.0         0.0
  24    1.350000 02    2.680000 02    1.565000 02    0.0         0.0         0.0
  25    1.350000 02    2.480000 02    1.565000 02    0.0         0.0         0.0
  26    1.800000 02    1.800000 02    1.800000 02    0.0         0.0         0.0
  27    1.800000 02    1.800000 02    1.800000 02    0.0         0.0         0.0
  28    1.800000 02    1.800000 02    1.800000 02    0.0         0.0         0.0
  29    1.800000 02    1.800000 02    1.800000 02    0.0         0.0         0.0
  30    1.800000 02    1.800000 02    1.800000 02    0.0         0.0         0.0
  31    1.800000 02    1.800000 02    1.800000 02    0.0         0.0         0.0
I,HEX(I),HEY(I),HEZ(I)
   1    0.0            0.0            0.0
   2    0.0            0.0            0.0
   3    0.0            0.0            0.0
   4    0.0            0.0            0.0
   5    0.0            0.0            0.0
   6    0.0            0.0            0.0
   7    0.0            0.0            0.0
   8    0.0            0.0            0.0
   9    0.0            0.0            0.0
  10    0.0            0.0            0.0
  11    0.0            0.0            0.0
  12    0.0            0.0            0.0
  13    0.0            0.0            0.0
  14    0.0            0.0            0.0
  15    0.0            0.0            0.0
  16    0.0            0.0            0.0
  17    0.0            0.0            0.0
```

CARD 100
CARD 101

CARDS 200-238

CARDS 300-305

CARDS 310-340

CARDS 400-415

Figure 16. Sample 31 Mars Case Input Data.

```
   18    0.0              0.0              0.0
   19    0.0              0.0              0.0
   20    0.0              0.0              0.0
   21    0.0              0.0              0.0
   22    0.0              0.0              0.0
   23    0.0              0.0              0.0
   24    0.0              0.0              0.0
   25    0.0              0.0              0.0
   26    0.0              0.0              0.0
   27    0.0              0.0              0.0
   28    0.0              0.0              0.0
   29    0.0              0.0              0.0
   30    0.0              0.0              0.0
   31    0.0              0.0              0.0
FLIFT
   0.0              0.0              0.0              0.0              0.0              0.0
   0.0              0.0              0.0              0.0              0.0              0.0
   0.0              0.0              0.0              0.0              0.0              0.0        CARDS 450-455
   0.0              0.0              0.0              0.0              0.0              0.0
   0.0              0.0              0.0              0.0              0.0              0.0
   0.0
XGDOT,YGDOT,ZGDOT
   0.0             -2.232000D 02    2.760000D 02                                                   CARD 460
PPR,QPR,RPR
   4.615000D-01     0.0             0.0                                                            CARD 461
PHIPR,THEPR,PSIPR
  -1.744000D-01    -1.746000D-02    0.0                                                            CARD 462
I,XBP(I),YBP(I),ZBP(I)
    1    4.587500D 02    0.0                  1.325200D 02
    2    4.044300D 02    0.0                  7.200000D 01
    3    2.418290D 02    0.0                  4.792000D 01
    4    2.130000D 02    0.0                  3.045000D 01
    5    1.630050D 02    0.0                  3.045000D 01
    6    1.410000D 02    0.0                  3.045000D 01
    7    1.470200D 02    0.0                  3.000000D 01
    8    1.365000D 02    0.0                  9.000000D 01
    9    1.410000D 02    0.0                  6.700000D 01
   10    1.630000D 02    0.0                  2.200000D 01
   11    1.410000D 02    0.0                  2.200000D 01
   12    7.163000D 01   -4.500000D 01         2.200000D 01
   13    7.163000D 01    4.500000D 01         2.200000D 01
   14    1.630000D 02   -5.000000D 01        -7.000000D 00
   15    1.630000D 02    5.000000D 01        -7.000000D 00
   16    7.162030D 01    0.0                  2.200000D 01
   17    7.162000D 01   -5.000000D 01        -7.000000D 00                                         CARDS 470-485
   18    7.162000D 01    5.000000D 01        -7.000000D 00
   19    2.300000D 01    0.0                  2.300000D 01
   20    1.630000D 02   -4.500000D 01         7.600000D 01
   21    1.630000D 02    4.500000D 01         7.600000D 01
   22    1.630000D 02   -4.500000D 01         2.200000D 01
   23    1.630000D 02    4.500000D 01         2.200000D 01
   24    7.162000D 01   -4.500000D 01         7.600000D 01
   25    7.162000D 01    4.500000D 01         7.600000D 01
   26    1.620000D 02    0.0                  3.200000D 01
   27    7.162000D 01    0.0                  3.200000D 01
   28    1.620000D 02    0.0                  4.200000D 01
   29    7.162000D 01    0.0                  4.200000D 01
   30    1.630000D 02    0.0                  4.200000D 01
   31    7.162000D 01    0.0                  4.200000D 01
 I,PHIOP(I),THEOP(I),PSIOP(I)
    1    0.0              0.0              0.0
    2    0.0              0.0              0.0
    3    0.0              0.0              0.0
    4    0.0              0.0              0.0
    5    0.0              0.0              0.0
    6    0.0              0.0              0.0
    7    0.0              0.0              0.0
    8    0.0              0.0              0.0
    9    0.0              0.0              0.0
   10    0.0              0.0              0.0
   11    0.0              0.0              0.0
   12    0.0              0.0              0.0
   13    0.0              0.0              0.0
   14    0.0              0.0              0.0
   15    0.0              0.0              0.0                                                   CARDS 500-515
   16    0.0              0.0              0.0
   17    0.0              0.0              0.0
   18    0.0              0.0              0.0
   19    0.0              0.0              0.0
   20    0.0              0.0              0.0
   21    0.0              0.0              0.0
   22    0.0              0.0              0.0
   23    0.0              0.0              0.0
   24    0.0              0.0              0.0
   25    0.0              0.0              0.0
   26    0.0              0.0              0.0
   27    0.0              0.0              0.0
   28    0.0              0.0              0.0
   29    0.0              0.0              0.0
   30    0.0              0.0              0.0
   31    0.0              0.0              0.0
 I, LEAR (I,1), LEAR (I,2), LEAR (I,3)
    1    0.0              0.0              0.0
    2    0.0              0.0              0.0
    3    0.0              0.0              0.0
    4    0.0              0.0              0.0
```

Figure 16. (Continued)

```
  5   0.0            0.0            0.0
  6   0.0            0.0            0.0
  7   0.0            0.0            0.0
  8   0.0            0.0            0.0
  9   0.0            0.0            0.0
 10   0.0            0.0            1.700000 01
 11   0.0            0.0            1.700000 01
 12   0.0            1.000000 01    1.700000 01
 13   0.0            0.0            1.700000 01
 14   0.0            3.000000 00    2.250000 00
 15   0.0            0.0            2.250000 00
 16   0.0            0.0            1.700000 01
 17   0.0            3.000000 00    2.250000 00
 18   0.0            0.0            2.250000 00
 19   0.0            0.0            0.0
 20   0.0            1.000000 01    0.0
 21   0.0            0.0            0.0
 22   0.0            1.000000 01    1.700000 01
 23   0.0            0.0            1.700000 01
 24   0.0            1.000000 01    0.0
 25   0.0            0.0            0.0
 26   0.0            0.0            0.0
 27   0.0            0.0            0.0
 28   0.0            0.0            0.0
 29   0.0            0.0            0.0
 30   0.0            0.0            0.0
 31   0.0            0.0            0.0
```

CARDS 600-615

```
I, SP (I,1), SP (I,2), SP (I,3)
  1    0    0    0
  2    0    0    0
  3    0    0    0
  4    0    0    0
  5    0    0    0
  6    0    0    0
  7    0    0    0
  8    0    0    0
  9    0    0    0
 10    0    0    1
 11    0    0    1
 12    0    0    1
 13    0    0    1
 14    0    0    1
 15    0    0    1
 16    0    0    1
 17    0    0    1
 18    0    0    1
 19    0    0    0
 20    0    0    0
 21    0    0    0
 22    0    0    1
 23    0    0    1
 24    0    0    0
 25    0    0    0
 26    0    0    0
 27    0    0    0
 28    0    0    0
 29    0    0    0
 30    0    0    0
 31    0    0    0
```

CARDS 700-703

```
I, MU (I,1), MU (I,2), MU (I,3)
  1   0.0            0.0            0.0
  2   0.0            0.0            0.0
  3   0.0            0.0            0.0
  4   0.0            0.0            0.0
  5   0.0            0.0            0.0
  6   0.0            0.0            0.0
  7   0.0            0.0            0.0
  8   0.0            0.0            0.0
  9   0.0            0.0            0.0
 10   0.0            0.0            3.000000-01
 11   0.0            0.0            3.000000-01
 12   0.0            3.000000-01    3.000000-01
 13   0.0            0.0            3.000000-01
 14   0.0            3.000000-01    3.000000-01
 15   0.0            0.0            3.000000-01
 16   0.0            0.0            3.000000-01
 17   0.0            2.000000-01    3.000000-01
 18   0.0            0.0            3.000000-01
 19   0.0            0.0            0.0
 20   0.0            3.000000-01    0.0
 21   0.0            0.0            0.0
 22   0.0            1.000000-01    3.000000-01
 23   0.0            0.0            3.000000-01
 24   0.0            1.000000-01    0.0
 25   0.0            0.0            0.0
 26   0.0            0.0            0.0
 27   0.0            0.0            0.0
 28   0.0            0.0            0.0
 29   0.0            0.0            0.0
 30   0.0            0.0            0.0
 31   0.0            0.0            0.0
```

CARDS 710-725

Figure 16. (Continued)

```
I, KE (I,1), KE (I,2), KE (I,3)
  1    0.0          0.0          0.0
  2    0.0          0.0          0.0
  3    0.0          0.0          0.0
  4    0.0          0.0          0.0
  5    0.0          0.0          0.0
  6    0.0          0.0          0.0
  7    0.0          0.0          0.0
  8    0.0          0.0          0.0
  9    0.0          0.0          0.0
 10    0.0          0.0          3.30000D 04
 11    0.0          0.0          1.10000D 04
 12    0.0          0.0          1.10000D 04
 13    0.0          0.0          1.10000D 04
 14    0.0          0.0          2.20000D 04
 15    0.0          0.0          2.20000D 04
 16    0.0          0.0          3.36000D 04
 17    0.0          2.20000D 04  2.20000D 04
 18    0.0          0.0          2.20000D 04
 19    0.0          0.0          0.0
 20    0.0          5.30000D 03  0.0
 21    0.0          0.0          0.0
 22    0.0          0.0          1.10000D 04
 23    0.0          0.0          1.10000D 04
 24    0.0          0.0          0.0
 25    0.0          0.0          0.0
 26    0.0          0.0          0.0
 27    0.0          0.0          0.0
 28    0.0          0.0          0.0
 29    0.0          0.0          0.0
 30    0.0          0.0          0.0
 31    0.0          0.0          0.0
```

CARDS 750-765

```
IJ,K, XX(1,K,IJ),XX(2,K,IJ),XX(3,K,IJ),XX(4,K,IJ),XX(5,K,IJ),XX(6,K,IJ)
  1   1  1.22770D 05   0.0           0.0           0.0           0.0           0.0
  1   2  0.0           1.75400D 03   0.0           0.0           0.0          -7.14390D 04
  1   3  0.0           0.0           2.22000D 03   0.0           9.04000D 04   0.0
  1   4  0.0           0.0           0.0           0.0           0.0           0.0
  1   5  0.0           0.0           9.04000D 04   0.0           4.91060D 06   0.0
  1   6  0.0          -7.14390D 04   0.0           0.0           0.0           3.87940D 06
  2   1  6.12750D 04   0.0           0.0           0.0           0.0           0.0
  2   2  0.0           6.50500D 03   0.0           0.0           0.0          -6.94000D 05
  2   3  0.0           0.0           9.66300D 03   0.0           7.88500D 05   0.0
  2   4  0.0           0.0           0.0           2.46400D 06   0.0           0.0
  2   5  0.0           0.0           7.88500D 05   0.0           8.97900D 07   0.0
  2   6  0.0          -6.94000D 05   0.0           0.0           0.0           7.95000D 07
  3   1  3.22400D 05   0.0           0.0           0.0           0.0           0.0
  3   2  0.0           1.21300D 06   0.0           0.0           0.0          -1.87900D 07
  3   3  0.0           0.0           1.63400D 06   0.0           2.53000D 07   0.0
  3   4  0.0           0.0           0.0           3.64900D 07   0.0           0.0
  3   5  0.0           0.0           2.53000D 07   0.0           5.22600D 08   0.0
  3   6  0.0          -1.87900D 07   0.0           0.0           0.0           3.28100D 08
  4   1  2.10100D 04   0.0           0.0           0.0           0.0           0.0
  4   2  0.0           8.55700D 05   0.0           0.0           0.0          -2.13200D 07
  4   3  0.0           0.0           4.77300D 06   0.0           1.13600D 08   0.0
  4   4  0.0           0.0           0.0           8.19300D 10   0.0           0.0
  4      0.0           0.0           1.13600D 08   0.0           3.60500D 09   0.0
  4   6  0.0          -2.13200D 07   0.0           0.0           0.0           6.76500D 08
  5   1  5.65000D 04   0.0           0.0           0.0           0.0           0.0
  5   2  0.0           1.12000D 05   0.0           0.0           0.0          -2.64000D 06
  5   3  0.0           0.0           1.12000D 05   0.0           2.64000D 06   0.0
  5   4  0.0           0.0           0.0           0.0           0.0           0.0
  5   5  0.0           0.0           2.64000D 06   0.0           8.29000D 07   0.0
  5   6  0.0          -2.64000D 06   0.0           0.0           0.0           8.29000D 07
  6   1  4.54500D 05   0.0           0.0           0.0           0.0           0.0
  6   2  0.0           1.66500D 06   0.0           0.0           0.0          -1.83200D 07
  6   3  0.0           0.0           5.55100D 06   0.0           6.08400D 07   0.0
  6   4  0.0           0.0           0.0           8.92400D 09   0.0           0.0
  6   5  0.0           0.0           6.08400D 07   0.0           8.92300D 08   0.0
  6   6  0.0          -1.83200D 07   0.0           0.0           0.0           2.68600D 08
  7   1  5.65000D 04   0.0           0.0           0.0           0.0           0.0
  7   2  0.0           1.12000D 05   0.0           0.0           0.0          -2.64000D 06
  7   3  0.0           0.0           1.12000D 05   0.0           2.64000D 06   0.0
  7   4  0.0           0.0           0.0           0.0           0.0           0.0
  7   5  0.0           0.0           2.64000D 06   0.0           8.29000D 07   0.0
  7   6  0.0          -2.64000D 06   0.0           0.0           0.0           8.29000D 07
  8   1  1.60000D 05   0.0           0.0           0.0           0.0           0.0
  8   2  0.0           0.0           0.0           0.0           0.0           0.0
  8   3  0.0           0.0           4.91600D 04   0.0           1.53700D 06   0.0
  8   4  0.0           0.0           0.0           0.0           0.0           0.0
  8   5  0.0           0.0           1.53700D 06   0.0           6.40100D 07   0.0
  8   6  0.0           0.0           0.0           0.0           0.0           0.0
  9   1  1.60000D 05   0.0           0.0           0.0           0.0           0.0
  9   2  0.0           0.0           0.0           0.0           0.0           0.0
  9   3  0.0           0.0           4.91600D 04   0.0           1.53700D 06   0.0
  9   4  0.0           0.0           0.0           0.0           0.0           0.0
  9   5  0.0           0.0           1.53700D 06   0.0           6.40100D 07   0.0
  9   6  0.0           0.0           0.0           0.0           0.0           0.0
 10   1  1.75400D 05   0.0           0.0           0.0           0.0           0.0
 10   2  0.0           0.0           0.0           0.0           0.0           0.0
 10   3  0.0           0.0           6.49800D 04   0.0           1.85000D 06   0.0
 10   4  0.0           0.0           0.0           0.0           0.0           0.0
 10   5  0.0           0.0           1.85000D 06   0.0           7.02400D 07   0.0
 10   6  0.0           0.0           0.0           0.0           0.0           0.0
 11   1  1.75400D 05   0.0           0.0           0.0           0.0           0.0
 11   2  0.0           0.0           0.0           0.0           0.0           0.0
 11   3  0.0           0.0           6.49800D 04   0.0           1.85000D 06   0.0
 11   4  0.0           0.0           0.0           0.0           0.0           0.0
 11   5  0.0           0.0           1.85000D 06   0.0           7.02400D 07   0.0
 11   6  0.0           0.0           0.0           0.0           0.0           0.0
```

CARDS 800-1027

Figure 16. (Continued)

```
12   1   3.040000 06    0.0            0.0            0.0            0.0            0.0
12   2   0.0            4.010000 05    0.0            0.0            0.0            -5.780000 04
12   3   0.0            0.0            3.250000 05    0.0            4.690000 06    0.0
12   4   0.0            0.0            0.0            2.560000 07    0.0            0.0
12   5   0.0            0.0            4.699000 06    0.0            8.950000 07    0.0
12   6   0.0            -5.780000 04   0.0            0.0            0.0            1.144000 06
13   1   4.863000 04    0.0            0.0            0.0            0.0            0.0
13   2   0.0            4.227000 06    0.0            0.0            0.0            -3.477000 07
13   3   0.0            0.0            3.424000 06    0.0            2.816000 07    0.0
13   4   0.0            0.0            0.0            8.267000 07    0.0            0.0
13   5   0.0            0.0            2.616000 07    0.0            3.088000 08    0.0
13   6   0.0            -3.477000 07   0.0            0.0            0.0            3.813000 08
14   1   0.0            0.0            0.0            0.0            0.0            0.0
14   2   0.0            0.0            0.0            0.0            0.0            0.0
14   3   0.0            0.0            0.0            0.0            0.0            0.0
14   4   0.0            0.0            0.0            2.190000 06    0.0            0.0
14   5   0.0            0.0            0.0            0.0            0.0            0.0
14   6   0.0            0.0            0.0            0.0            0.0            0.0
15   1   2.939000 06    0.0            0.0            0.0            0.0            0.0
15   2   0.0            1.051000 05    0.0            0.0            0.0            -2.422000 06
15   3   0.0            0.0            1.911000 04    0.0            4.404000 05    0.0
15   4   0.0            0.0            0.0            2.256000 06    0.0            0.0
15   5   0.0            0.0            4.404000 05    0.0            1.354000 07    0.0
15   6   0.0            -2.422000 06   0.0            0.0            0.0            7.443000 07
16   1   5.455000 05    0.0            0.0            0.0            0.0            0.0
16   2   0.0            4.869000 05    0.0            0.0            0.0            -5.359000 06
16   3   0.0            0.0            1.003000 05    0.0            1.903000 06    0.0
16   4   0.0            0.0            0.0            2.360000 06    0.0            0.0
16   5   0.0            0.0            1.903000 06    0.0            2.509000 07    0.0
16   6   0.0            -5.359000 06   0.0            0.0            0.0            7.059000 07
17   1   4.795000 05    0.0            0.0            0.0            0.0            0.0
17   2   0.0            2.697000 03    0.0            0.0            0.0            -6.637000 04
17   3   0.0            0.0            2.697000 03    0.0            6.637000 04    0.0
17   4   0.0            0.0            0.0            9.587000 07    0.0            0.0
17   5   0.0            0.0            6.637000 04    0.0            2.178000 06    0.0
17   6   0.0            -6.637000 04   0.0            0.0            0.0            2.178000 06
18   1   4.795000 05    0.0            0.0            0.0            0.0            0.0
18   2   0.0            2.697000 03    0.0            0.0            0.0            -6.637000 04
18   3   0.0            0.0            2.697000 03    0.0            6.637000 04    0.0
18   4   0.0            0.0            0.0            9.587000 07    0.0            0.0
18   5   0.0            0.0            6.637000 04    0.0            2.178000 06    0.0
18   6   0.0            -6.637000 04   0.0            0.0            0.0            2.178000 06
19   1   8.809000 04    0.0            0.0            0.0            0.0            0.0
19   2   0.0            2.239000 04    0.0            0.0            0.0            -5.037000 05
19   3   0.0            0.0            1.317000 05    0.0            2.963000 06    0.0
19   4   0.0            0.0            0.0            0.0            0.0            0.0
19   5   0.0            0.0            2.963000 06    0.0            8.809000 07    0.0
19   6   0.0            -5.037000 05   0.0            0.0            0.0            1.951000 07
20   1   8.809000 04    0.0            0.0            0.0            0.0            0.0
20   2   0.0            2.239000 04    0.0            0.0            0.0            -5.037000 05
20   3   0.0            0.0            1.317000 05    0.0            2.963000 06    0.0
20   4   0.0            0.0            0.0            0.0            0.0            0.0
20   5   0.0            0.0            2.963000 06    0.0            8.809000 07    0.0
20   6   0.0            -5.037000 05   0.0            0.0            0.0            1.951000 07
21   1   1.730000 05    0.0            0.0            0.0            0.0            0.0
21   2   0.0            1.545000 06    0.0            0.0            0.0            -5.359000 07
21   3   0.0            0.0            5.707000 03    0.0            1.994000 05    0.0
21   4   0.0            0.0            0.0            7.509000 05    0.0            0.0
21   5   0.0            0.0            1.994000 05    0.0            9.225000 06    0.0
21   6   0.0            -5.359000 07   0.0            0.0            0.0            2.479000 09
22   1   1.770000 06    0.0            0.0            0.0            0.0            0.0
22   2   0.0            1.275000 05    0.0            0.0            0.0            -2.060000 06
22   3   0.0            0.0            2.123000 04    0.0            4.776000 05    0.0
22   4   0.0            0.0            0.0            1.067000 06    0.0            0.0
22   5   0.0            0.0            4.776000 05    0.0            1.433000 07    0.0
22   6   0.0            -2.060000 06   0.0            0.0            0.0            8.604000 07
23   1   1.481000 05    0.0            0.0            0.0            0.0            0.0
23   2   0.0            5.611000 03    0.0            0.0            0.0            -1.461000 05
23   3   0.0            0.0            7.377000 04    0.0            1.992000 06    0.0
23   4   0.0            0.0            0.0            2.901000 05    0.0            0.0
23   5   0.0            0.0            1.992000 06    0.0            7.170000 07    0.0
23   6   0.0            -1.461000 05   0.0            0.0            0.0            5.259000 06
24   1   1.770000 06    0.0            0.0            0.0            0.0            0.0
24   2   0.0            1.275000 05    0.0            0.0            0.0            -2.060000 06
24   3   0.0            0.0            2.123000 04    0.0            4.776000 05    0.0
24   4   0.0            0.0            0.0            1.067000 06    0.0            0.0
24   5   0.0            0.0            4.776000 05    0.0            1.433000 07    0.0
24   6   0.0            -2.060000 06   0.0            0.0            0.0            8.604000 07
25   1   1.481000 05    0.0            0.0            0.0            0.0            0.0
25   2   0.0            5.411000 03    0.0            0.0            0.0            -1.461000 05
25   3   0.0            0.0            7.377000 04    0.0            1.992000 06    0.0
25   4   0.0            0.0            0.0            2.901000 05    0.0            0.0
25   5   0.0            0.0            1.992000 06    0.0            7.170000 07    0.0
25   6   0.0            -1.461000 05   0.0            0.0            0.0            5.259000 06
26   1   2.397000 05    0.0            0.0            0.0            0.0            0.0
26   2   0.0            1.429000 03    0.0            0.0            0.0            -3.516000 04
26   3   0.0            0.0            1.429000 03    0.0            3.516000 04    0.0
26   4   0.0            0.0            0.0            2.546000 07    0.0            0.0
26   5   0.0            0.0            3.516000 04    0.0            1.154000 06    0.0
26   6   0.0            -3.516000 04   0.0            0.0            0.0            1.154000 06
27   1   2.397000 05    0.0            0.0            0.0            0.0            0.0
27   2   0.0            1.429000 03    0.0            0.0            0.0            -3.516000 04
27   3   0.0            0.0            1.429000 03    0.0            3.516000 04    0.0
27   4   0.0            0.0            0.0            2.546000 07    0.0            0.0
27   5   0.0            0.0            3.516000 04    0.0            1.154000 06    0.0
27   6   0.0            -3.516000 04   0.0            0.0            0.0            1.154000 06
```

CARDS 800-1027

Figure 16. (Continued)

```
28   1   2.537000 05   0.0           0.0           0.0           0.0           0.0
28   2   0.0           8.933000 06   0.0           0.0           0.0          -2.172000 06
28   3   0.0           0.0           9.148000 04   0.0           2.234000 06   0.0
28   4   0.0           0.0           0.0           1.072000 06   0.0           0.0
28   5   0.0           0.0           2.234000 06   0.0           7.260000 07   0.0
28   6   0.0          -2.172000 06   0.0           0.0           0.0           7.039000 07
29   1   4.445000 04   0.0           0.0           0.0           0.0           0.0
29   2   0.0           2.500000 05   0.0           0.0           0.0          -1.260000 05
29   3   0.0           0.0           1.647000 04   0.0           7.410000 05   0.0
29   4   0.0           0.0           0.0           0.0           0.0           0.0
29   5   0.0           0.0           7.410000 05   0.0           4.445000 07   0.0
29   6   0.0          -1.260000 05   0.0           0.0           0.0           7.559000 06
30   1   7.427000 04   0.0           0.0           0.0           0.0           0.0
30   2   0.0           7.621000 04   0.0           0.0           0.0          -2.058000 06
30   3   0.0           0.0           1.296000 04   0.0           3.498000 05   0.0
30   4   0.0           0.0           0.0           0.0           0.0           0.0
30   5   0.0           0.0           3.498000 05   0.0           1.259000 07   0.0
30   6   0.0          -2.058000 06   0.0           0.0           0.0           7.407000 07
31   1   7.407000 04   0.0           0.0           0.0           0.0           0.0
31   2   0.0           7.621000 04   0.0           0.0           0.0          -2.058000 06
31   3   0.0           0.0           1.296000 04   0.0           3.498000 05   0.0
31   4   0.0           0.0           0.0           0.0           0.0           0.0
31   5   0.0           0.0           3.498000 05   0.0           1.259000 07   0.0
31   6   0.0          -2.058000 06   0.0           0.0           0.0           7.407000 07
32   1   8.890000 05   0.0           0.0           0.0           0.0           0.0
32   2   0.0           3.960000 03   0.0           0.0           0.0          -1.792000 05
32   3   0.0           0.0           3.045000 02   0.0           1.370000 04   0.0
32   4   0.0           0.0           0.0           6.550000 04   0.0           0.0
32   5   0.0           0.0           1.370000 04   0.0           8.220000 05   0.0
32   6   0.0          -1.792000 05   0.0           0.0           0.0           1.075000 07
33   1   1.000000 04   0.0           0.0           0.0           0.0           0.0
33   2   0.0           1.000000 05   0.0           0.0           0.0          -1.000000 05
33   3   0.0           0.0           1.000000 05   0.0           1.000000 05   0.0
33   4   0.0           0.0           0.0           1.000000 06   0.0           0.0
33   5   0.0           0.0           1.000000 05   0.0           1.000000 07   0.0
33   6   0.0          -1.000000 05   0.0           0.0           0.0           1.000000 07
34   1   3.000000 04   0.0           0.0           0.0           0.0           0.0
34   2   0.0           1.000000 05   0.0           0.0           0.0          -1.000000 05
34   3   0.0           0.0           1.000000 05   0.0           1.000000 05   0.0
34   4   0.0           0.0           0.0           1.000000 06   0.0           0.0
34   5   0.0           0.0           1.000000 05   0.0           1.000000 07   0.0
34   6   0.0          -1.000000 05   0.0           0.0           0.0           1.000000 07
35   1   1.229000 03   0.0           0.0           0.0           0.0           0.0
35   2   0.0           1.000000 05   0.0           0.0           0.0          -1.000000 05
35   3   0.0           0.0           1.000000 05   0.0           1.000000 05   0.0
35   4   0.0           0.0           0.0           1.000000 06   0.0           0.0
35   5   0.0           0.0           1.000000 05   0.0           1.000000 07   0.0
35   6   0.0          -1.000000 05   0.0           0.0           0.0           1.000000 07
36   1   1.229000 03   0.0           0.0           0.0           0.0           0.0
36   2   0.0           1.000000 05   0.0           0.0           0.0          -1.000000 05
36   3   0.0           0.0           1.000000 05   0.0           1.000000 05   0.0
36   4   0.0           0.0           0.0           1.000000 06   0.0           0.0
36   5   0.0           0.0           1.000000 05   0.0           1.000000 07   0.0
36   6   0.0          -1.000000 05   0.0           0.0           0.0           1.000000 07
37   1   7.800000 02   0.0           0.0           0.0           0.0           0.0
37   2   0.0           1.000000 05   0.0           0.0           0.0          -1.000000 05
37   3   0.0           0.0           1.000000 05   0.0           1.000000 05   0.0
37   4   0.0           0.0           0.0           1.000000 06   0.0           0.0
37   5   0.0           0.0           1.000000 05   0.0           1.000000 07   0.0
37   6   0.0          -1.000000 05   0.0           0.0           0.0           1.000000 07
38   1   7.660000 02   0.0           0.0           0.0           0.0           0.0
38   2   0.0           1.000000 05   0.0           0.0           0.0          -1.000000 05
38   3   0.0           0.0           1.000000 05   0.0           1.000000 05   0.0
38   4   0.0           0.0           0.0           1.000000 06   0.0           0.0
38   5   0.0           0.0           1.000000 05   0.0           1.000000 07   0.0
38   6   0.0          -1.000000 05   0.0           0.0           0.0           1.000000 07
```

CARDS 800-1027

```
I,  VMAX(1,I),VMAX(2,I),VMAX(3,I),VMAX(4,I),VMAX(5,I),VMAX(6,I)
  1    1.000000 01   1.000000 01   7.000000 01   1.000000 01   1.000000 01   1.000000 01
  2    1.000000 01   6.000000 00   6.000000 00   1.000000 01   1.000000 01   1.000000 01
  3    1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01
  4    1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01
  5    1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01
  6    1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01
  7    1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01
  8    1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01
  9    1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01
 10    1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01
 11    1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01
 12    1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01
 13    1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01
 14    1.000000 00   1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01
 15    1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01
 16    1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01
 17    1.000000 01   1.000000 01   1.510000 01   1.000000 01   1.000000 01   1.000000 01
 18    1.000000 01   1.000000 01   1.510000 01   1.000000 01   1.000000 01   1.000000 01
 19    1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01
 20    1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01
 21    1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01
 22    1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01
 23    1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01
 24    1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01
 25    1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01
 26    1.000000 01   1.000000 01   1.510000 01   1.000000 01   1.000000 01   1.000000 01
 27    1.000000 01   1.000000 01   1.510000 01   1.000000 01   1.000000 01   1.000000 01
 28    1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01
 29    1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01
 30    1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01
 31    1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01
 32    1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01
 33    1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01   1.000000 01
```

CARDS 2000-2037

Figure 16. (Continued)

```
 34    1.000000 01    1.000000 01    1.000000 01    1.000000 01    1.000000 01    1.000000 01
 35    1.000000 01    1.000000 01    1.000000 01    1.000000 01    1.000000 01    1.000000 01
 36    1.000000 01    1.000000 01    1.000000 01    1.000000 01    1.000000 01    1.000000 01
 37    1.000000 01    1.000000 01    1.000000 01    1.000000 01    1.000000 01    1.000000 01
 38    1.000000 01    1.000000 01    1.000000 01    1.000000 01    1.000000 01    1.000000 01
DR(L,IJ) FOR KR TABLES
   1.000000 00   1.000000 00   1.000000 00   1.000000 00   5.000000 00   1.000000 00
   1.000000 00   2.000000 00   2.000000 00   1.000000 00   1.000000 00   1.000000 00
   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
   1.000000-01   6.670000-02   6.670000-02   1.000000-01   1.000000-01   1.000000-01
   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
   1.000000-01   6.670000-02   6.670000-02   1.000000-01   1.000000-01   1.000000-01
   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
   1.000000 00   5.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
   4.000000-01   2.000000-01   2.000000-01   1.000000-01   5.500000-03   1.000000-01
   1.500000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
   5.000000-01   4.000000 00   4.000000 00   2.000000-01   2.000000-01   2.000000-01
   5.000000-01   4.000000 00   4.000000 00   2.000000-01   2.000000-01   2.000000-01
   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
   5.000000-01   4.000000 00   4.000000 00   2.000000-01   2.000000-01   2.000000-01
   5.000000-01   4.000000 00   4.000000 00   2.000000-01   2.000000-01   2.000000-01
   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
   1.000000 00   2.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
```

CARDS 2100-2137

```
IJ,L,KR(1,L,IJ),KR(2,L,IJ),KR(3,L,IJ),KR(4,L,IJ),KR(5,L,IJ),KR(6,L,IJ)
   1    1    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
   1    2    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
   1    3    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
   1    4    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
   1    5    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
   1    6    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
   2    1    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
   2    2    1.000000 00    1.000000 00   -1.000000 00   -1.000000 00   -1.000000 00   -1.000000 00
   2    3    1.000000 00    1.000000 00   -1.000000 00   -1.000000 00   -1.000000 00   -1.000000 00
   2    4    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
   2    5    1.000000 00    1.000000 00    0.0           -1.000000 00   -1.000000 00   -1.000000 00
   2    6    1.000000 00    1.000000 00    0.0           -1.000000 00   -1.000000 00   -1.000000 00
   3    1    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
   3    2    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
   3    3    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
   3    4    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
   3    5    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
   3    6    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
   4    1    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
   4    2    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
   4    3    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
   4    4    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
   4    5    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
   4    6    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
   5    1    1.000000 00    1.000000 00   -7.000000-01   -7.000000-01    0.0            0.0
   5    2    1.000000 00    1.000000 00    1.000000 00    1.000000 00    0.0            0.0
   5    3    1.000000 00    1.000000 00    1.000000 00    1.000000 00    0.0            0.0
   5    4    1.000000 00    1.000000 00    1.000000 00    1.000000 00    0.0            0.0
   5    5    1.000000 00    1.000000 00    1.000000 00    1.000000 00    0.0            0.0
   5    6    1.000000 00    1.000000 00    1.000000 00    1.000000 00    0.0            0.0
   6    1    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
   6    2    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
   6    3    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
   6    4    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
   6    5    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
   6    6    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
   7    1    1.000000 00    1.000000 00   -7.000000-01   -7.000000-01    0.0            0.0
   7    2    1.000000 00    1.000000 00    1.000000 00    1.000000 00    0.0            0.0
   7    3    1.000000 00    1.000000 00    1.000000 00    1.000000 00    0.0            0.0
   7    4    1.000000 00    1.000000 00    1.000000 00    1.000000 00    0.0            0.0
   7    5    1.000000 00    1.000000 00    1.000000 00    1.000000 00    0.0            0.0
   7    6    1.000000 00    1.000000 00    1.000000 00    1.000000 00    0.0            0.0
   8    1    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
   8    2    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
   8    3    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
   8    4    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
   8    5    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
   8    6    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
   9    1    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
   9    2    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
   9    3    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
   9    4    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
   9    5    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
   9    6    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00    1.000000 00
```

CARDS 2201-2428

Figure 16. (Continued)

```
10   1   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
10   2   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
10   3   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
10   4   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
10   5   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
10   6   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
11   1   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
11   2   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
11   3   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
11   4   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
11   5   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
11   6   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
12   1   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
12   2   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
12   3   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
12   4   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
12   5   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
12   6   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
13   1   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
13   2   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
13   3   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
13   4   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
13   5   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
13   6   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
14   1   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
14   2   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
14   3   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
14   4   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
14   5   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
14   6   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
15   1   7.850000-03   7.850000-03   1.000000 00   1.000000 00   0.0           0.0
15   2   1.000000 00   1.000000 00   1.000000 00   1.000000 00   0.0           0.0
15   3   1.000000 00   1.000000 00   1.000000 00   1.000000 00   0.0           0.0
15   4   1.000000 00   1.000000 00   1.000000 00   1.000000 00   0.0           0.0
15   5   1.000000 00   1.000000 00   1.000000 00   1.000000 00   0.0           0.0
15   6   1.000000 00   1.000000 00   1.000000 00   1.000000 00   0.0           0.0
16   1   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
16   2   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
16   3   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
16   4   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
16   5   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
16   6   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
17   1   1.000000 00   1.000000 00   1.000000 00   1.000000 00  -3.330000 00  -3.330000 00
-----------------------------------------------------------------------------------------
17   2   1.000000 00   1.000000 00   1.000000 00   1.000000 00  -3.330000 00  -3.330000 00
17   3   1.000000 00   1.000000 00   1.000000 00   1.000000 00  -3.330000 00  -3.330000 00
17   4   1.000000 00   1.000000 00   1.000000 00   1.000000 00  -3.330000 00  -3.330000 00
17   5   1.000000 00   1.000000 00   1.000000 00   1.000000 00  -3.330000 00  -3.330000 00
17   6   1.000000 00   1.000000 00   1.000000 00   1.000000 00  -3.330000 00  -3.330000 00
18   1   1.000000 00   1.000000 00   1.000000 00   1.000000 00  -3.330000 00  -3.330000 00
18   2   1.000000 00   1.000000 00   1.000000 00   1.000000 00  -3.330000 00  -3.330000 00
18   3   1.000000 00   1.000000 00   1.000000 00   1.000000 00  -3.330000 00  -3.330000 00
18   4   1.000000 00   1.000000 00   1.000000 00   1.000000 00  -3.330000 00  -3.330000 00
18   5   1.000000 00   1.000000 00   1.000000 00   1.000000 00  -3.330000 00  -3.330000 00
18   6   1.000000 00   1.000000 00   1.000000 00   1.000000 00  -3.330000 00  -3.330000 00
19   1   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
19   2   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
19   3   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
19   4   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
19   5   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
19   6   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
20   1   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
20   2   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
20   3   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
20   4   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
20   5   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
20   6   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
21   1   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
21   2   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
21   3   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
21   4   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
21   5   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
21   6   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
22   1   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
22   2   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
22   3   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
22   4   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
22   5   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
22   6   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
23   1   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
23   2   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
23   3   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
23   4   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
23   5   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
23   6   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
24   1   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
24   2   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
24   3   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
24   4   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
24   5   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
24   6   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
25   1   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
25   2   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
25   3   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
25   4   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
25   5   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
25   6   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
```

CARDS 2201-2428

Figure 16. (Continued)

```
26   1   1.000000 00   1.000000 00   1.000000 00   1.000000 00   -3.330000 00   -3.330000 00
26   2   1.000000 00   1.000000 00   1.000000 00   1.000000 00   -3.330000 00   -3.330000 00
26   3   1.000000 00   1.000000 00   1.000000 00   1.000000 00   -3.330000 00   -3.330000 00
26   4   1.000000 00   1.000000 00   1.000000 00   1.000000 00   -3.330000 00   -3.330000 00
26   5   1.000000 00   1.000000 00   1.000000 00   1.000000 00   -3.330000 00   -3.330000 00
26   6   1.000000 00   1.000000 00   1.000000 00   1.000000 00   -3.330000 00   -3.330000 00
27   1   1.000000 00   1.000000 00   1.000000 00   1.000000 00   -3.330000 00   -3.330000 00
27   2   1.000000 00   1.000000 00   1.000000 00   1.000000 00   -3.330000 00   -3.330000 00
27   3   1.000000 00   1.000000 00   1.000000 00   1.000000 00   -3.330000 00   -3.330000 00
27   4   1.000000 00   1.000000 00   1.000000 00   1.000000 00   -3.330000 00   -3.330000 00
27   5   1.000000 00   1.000000 00   1.000000 00   1.000000 00   -3.330000 00   -3.330000 00
27   6   1.000000 00   1.000000 00   1.000000 00   1.000000 00   -3.330000 00   -3.330000 00
28   1   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
28   2   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
28   3   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
28   4   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
28   5   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
28   6   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
29   1   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
29   2   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
29   3   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
29   4   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
29   5   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
29   6   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
30   1   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
30   2   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
30   3   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
30   4   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
30   5   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
30   6   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
31   1   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00    .000000 00
31   2   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
31   3   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
31   4   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
31   5   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
31   6   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
32   1   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
32   2   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
32   3   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
32   4   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
32   5   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
32   6   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
33   1   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
33   2   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
33   3   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
33   4   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
33   5   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
33   6   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
34   1   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
34   2   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
34   3   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
34   4   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
34   5   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
34   6   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
35   1   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
35   2   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
35   3   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
35   4   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
35   5   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
35   6   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
36   1   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
36   2   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
36   3   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
36   4   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
36   5   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
36   6   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
37   1   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
37   2   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
37   3   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
37   4   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
37   5   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
37   6   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
38   1   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
38   2   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
38   3   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
38   4   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
38   5   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
38   6   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00   1.000000 00
```

CARDS 2201-2426

Figure 16. (Continued)

```
I,K, STI(I,K),SA(I,K),SN(I,K),SF(I,K),FSPC(I,K),         FSPDF(I,K)
  1    1   0.0            0.0            0.0            0.0            0.0            0.0
  1    2   0.0            0.0            0.0            0.0            0.0            0.0
  1    3   0.0            0.0            0.0            0.0            0.0            0.0
  2    1   0.0            0.0            0.0            0.0            0.0            0.0
  2    2   0.0            0.0            0.0            0.0            0.0            0.0
  2    3   0.0            0.0            0.0            0.0            0.0            0.0
  3    1   0.0            0.0            0.0            0.0            0.0            0.0
  3    2   0.0            0.0            0.0            0.0            0.0            0.0
  3    3   0.0            0.0            0.0            0.0            0.0            0.0
  4    1   0.0            0.0            0.0            0.0            0.0            0.0
  4    2   0.0            0.0            0.0            0.0            0.0            0.0
  4    3   0.0            0.0            0.0            0.0            0.0            0.0
  5    1   0.0            0.0            0.0            0.0            0.0            0.0
  5    2   0.0            0.0            0.0            0.0            0.0            0.0
  5    3   0.0            0.0            0.0            0.0            0.0            0.0
  6    1   0.0            0.0            0.0            0.0            0.0            0.0
  6    2   0.0            0.0            0.0            0.0            0.0            0.0
  6    3   0.0            0.0            0.0            0.0            0.0            0.0
  7    1   0.0            0.0            0.0            0.0            0.0            0.0
  7    2   0.0            0.0            0.0            0.0            0.0            0.0
  7    3   0.0            0.0            0.0            0.0            0.0            0.0
  8    1   0.0            0.0            0.0            0.0            0.0            0.0
  8    2   0.0            0.0            0.0            0.0            0.0            0.0
  8    3   0.0            0.0            0.0            0.0            0.0            0.0
  9    1   0.0            0.0            0.0            0.0            0.0            0.0
  9    2   0.0            0.0            0.0            0.0            0.0            0.0
  9    3   0.0            0.0            0.0            0.0            0.0            0.0
 10    1   0.0            0.0            0.0            0.0            0.0            0.0
 10    2   0.0            0.0            0.0            0.0            0.0            0.0
 10    3   1.000000-03    1.000000 00    2.000000 00    3.500000 00    1.650000 04    1.650000 04
 11    1   0.0            0.0            0.0            0.0            0.0            0.0
 11    2   0.0            0.0            0.0            0.0            0.0            0.0
 11    3   1.000000-03    1.000000 00    2.000000 00    3.500000 00    9.500000 03    9.500000 03
 12    1   0.0            0.0            0.0            0.0            0.0            0.0
 12    2   0.0            0.0            0.0            0.0            0.0            0.0
 12    3   1.000000-03    1.000000 00    2.000000 00    3.500000 00    9.500000 03    9.500000 03
 13    1   0.0            0.0            0.0            0.0            0.0            0.0
 13    2   0.0            0.0            0.0            0.0            0.0            0.0
 13    3   1.000000-03    1.000000 00    2.000000 00    3.500000 00    9.500000 03    9.500000 03
 14    1   0.0            0.0            0.0            0.0            0.0            0.0
 14    2   0.0            0.0            0.0            0.0            0.0            0.0
 14    3   2.000000-01    4.000000-01    4.000000-01    1.200000 00    4.400000 03    4.400000 03
 15    1   0.0            0.0            0.0            0.0            0.0            0.0
 15    2   0.0            0.0            0.0            0.0            0.0            0.0
 15    3   2.000000-01    4.000000-01    4.000000-01    1.200000 00    4.400000 03    4.400000 03
 16    1   0.0            0.0            0.0            0.0            0.0            0.0
 16    2   0.0            0.0            0.0            0.0            0.0            0.0
 16    3   1.000000-03    1.000000 00    2.000000 00    3.500000 00    1.650000 04    1.650000 04
 17    1   0.0            0.0            0.0            0.0            0.0            0.0
 17    2   0.0            0.0            0.0            0.0            0.0            0.0
 17    3   2.000000-01    4.000000-01    4.000000-01    1.200000 00    4.400000 03    4.400000 03
 18    1   0.0            0.0            0.0            0.0            0.0            0.0
 18    2   0.0            0.0            0.0            0.0            0.0            0.0
 18    3   2.000000-01    4.000000-01    4.000000-01    1.200000 00    4.400000 03    4.400000 03
 19    1   0.0            0.0            0.0            0.0            0.0            0.0
 19    2   0.0            0.0            0.0            0.0            0.0            0.0
 19    3   0.0            0.0            0.0            0.0            0.0            0.0
 20    1   0.0            0.0            0.0            0.0            0.0            0.0
 20    2   0.0            0.0            0.0            0.0            0.0            0.0
 20    3   0.0            0.0            0.0            0.0            0.0            0.0
 21    1   0.0            0.0            0.0            0.0            0.0            0.0
 21    2   0.0            0.0            0.0            0.0            0.0            0.0
 21    3   0.0            0.0            0.0            0.0            0.0            0.0
 22    1   0.0            0.0            0.0            0.0            0.0            0.0
 22    2   0.0            0.0            0.0            0.0            0.0            0.0
 22    3   1.000000-03    1.000000 00    2.000000 00    3.500000 00    5.500000 03    5.500000 03
 23    1   0.0            0.0            0.0            0.0            0.0            0.0
 23    2   0.0            0.0            0.0            0.0            0.0            0.0
 23    3   1.000000-03    1.000000 00    2.000000 00    3.500000 00    5.500000 03    5.500000 03
 24    1   0.0            0.0            0.0            0.0            0.0            0.0
 24    2   0.0            0.0            0.0            0.0            0.0            0.0
 24    3   0.0            0.0            0.0            0.0            0.0            0.0
 25    1   0.0            0.0            0.0            0.0            0.0            0.0
 25    2   0.0            0.0            0.0            0.0            0.0            0.0
 25    3   0.0            0.0            0.0            0.0            0.0            0.0
 26    1   0.0            0.0            0.0            0.0            0.0            0.0
 26    2   0.0            0.0            0.0            0.0            0.0            0.0
 26    3   0.0            0.0            0.0            0.0            0.0            0.0
 27    1   0.0            0.0            0.0            0.0            0.0            0.0
 27    2   0.0            0.0            0.0            0.0            0.0            0.0
 27    3   0.0            0.0            0.0            0.0            0.0            0.0
 28    1   0.0            0.0            0.0            0.0            0.0            0.0
 28    2   0.0            0.0            0.0            0.0            0.0            0.0
 28    3   0.0            0.0            0.0            0.0            0.0            0.0
 29    1   0.0            0.0            0.0            0.0            0.0            0.0
 29    2   0.0            0.0            0.0            0.0            0.0            0.0
 29    3   0.0            0.0            0.0            0.0            0.0            0.0
 30    1   0.0            0.0            0.0            0.0            0.0            0.0
 30    2   0.0            0.0            0.0            0.0            0.0            0.0
 30    3   0.0            0.0            0.0            0.0            0.0            0.0
 31    1   0.0            0.0            0.0            0.0            0.0            0.0
 31    2   0.0            0.0            0.0            0.0            0.0            0.0
 31    3   0.0            0.0            0.0            0.0            0.0            0.0
```

CARDS 3000-3092

Figure 16. (Continued)

CARDS 3200-3206

```
I,J,CBARIJ
   1    2     5.000000-02
   2    3     5.000000-02
   3    4     5.000000-02
   4    5     5.000000-02
   4    7     5.000000-02
   5    6     5.000000-02
   5    7     5.000000-02
   5   20     5.000000-02
   5   21     5.000000-02
   5   22     1.000000-01
   5   23     1.000000-01
   6    9     5.000000-02
   6   11     1.000000+01
   7    8     5.000000-02
   8    9     5.000000-02
  10   11     1.000000-01
  10   14     1.000000-01
  10   15     1.000000-01
  10   22     1.000000-01
  10   23     1.000000-01
  11   16     1.000000-01
  12   14     1.000000-01
  12   24     5.000000-02
  13   16     1.000000-01
  13   25     5.000000-02
  16   17     1.000000-01
  16   18     1.000000-01
  16   19     1.000000-01
  20   21     5.900000-02
  20   22     5.000000-02
  21   23     5.000000-02
  24   25     5.000000-02
  19   26     5.000000-02
  16   27     5.000000-02
  26   28     2.470000-01
  27   29     2.300000-01
  26   30     1.010000-01
  27   31     1.792000-01

I,THETA(IJ),PSI(IJ)
   1    -8.379070-01    0.0
   2    -1.491810-01    0.0
   3    -2.963290-01    0.0
   4     0.0            0.0
   5     1.023640 00    0.0
   6     0.0            0.0
   7     2.507730 00    0.0
   8     6.953940-01    1.570800 00
   9     6.953940-01   -1.570800 00
  10    -3.504650-01    1.570800 00
  11    -3.504650-01   -1.570800 00
  12     1.570800 00    0.0
  13    -1.570800 00    0.0
  14    -2.497790-01    0.0
  15    -1.764500 00    0.0
  16     0.0            0.0
  17    -5.187220-01    1.570800 00
  18    -5.187220-01   -1.570800 00
  19     0.0            1.570800 00
  20     0.0           -1.570800 00
  21     0.0            0.0
  22     0.0           -1.570370 00
  23     1.570410 00    0.0
  24     0.0            1.370370 00
  25     1.570410 00    0.0
  26    -5.187220-01    1.570800 00
  27    -5.587220-01   -1.570800 00
  28     0.0            0.0
  29     0.0           -1.570800 00
  30    -1.570800 00    0.0
  31    -1.570800 00    0.0
  32     0.0           -1.570800 00
  33     1.570800 00    0.0
  34     1.570800 00    0.0
  35     1.570800 00    0.0
  36     1.570800 00    0.0
  37     1.570800 00    0.0
  38     1.570800 00    0.0
```

Figure [illegible]. (Continued)

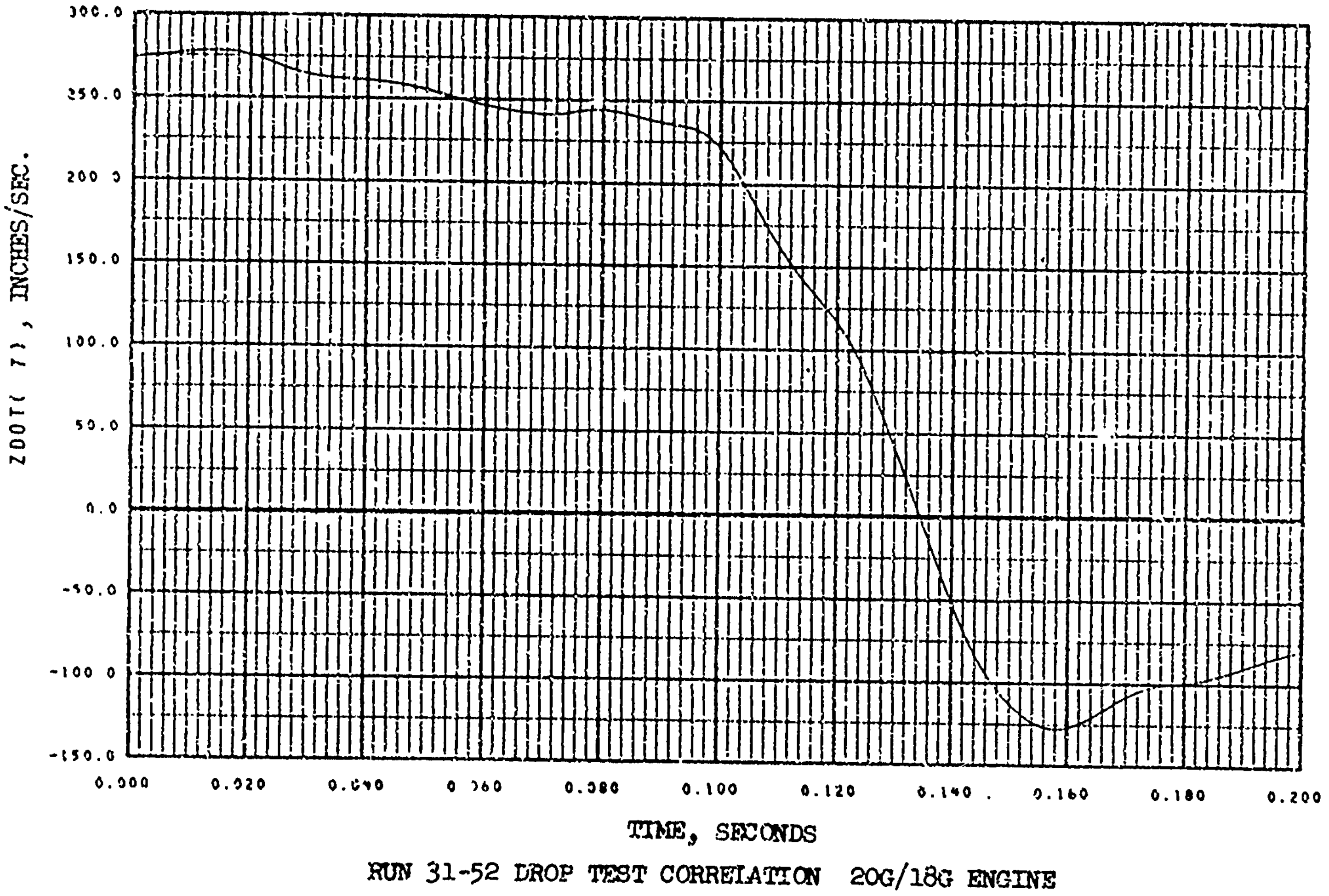
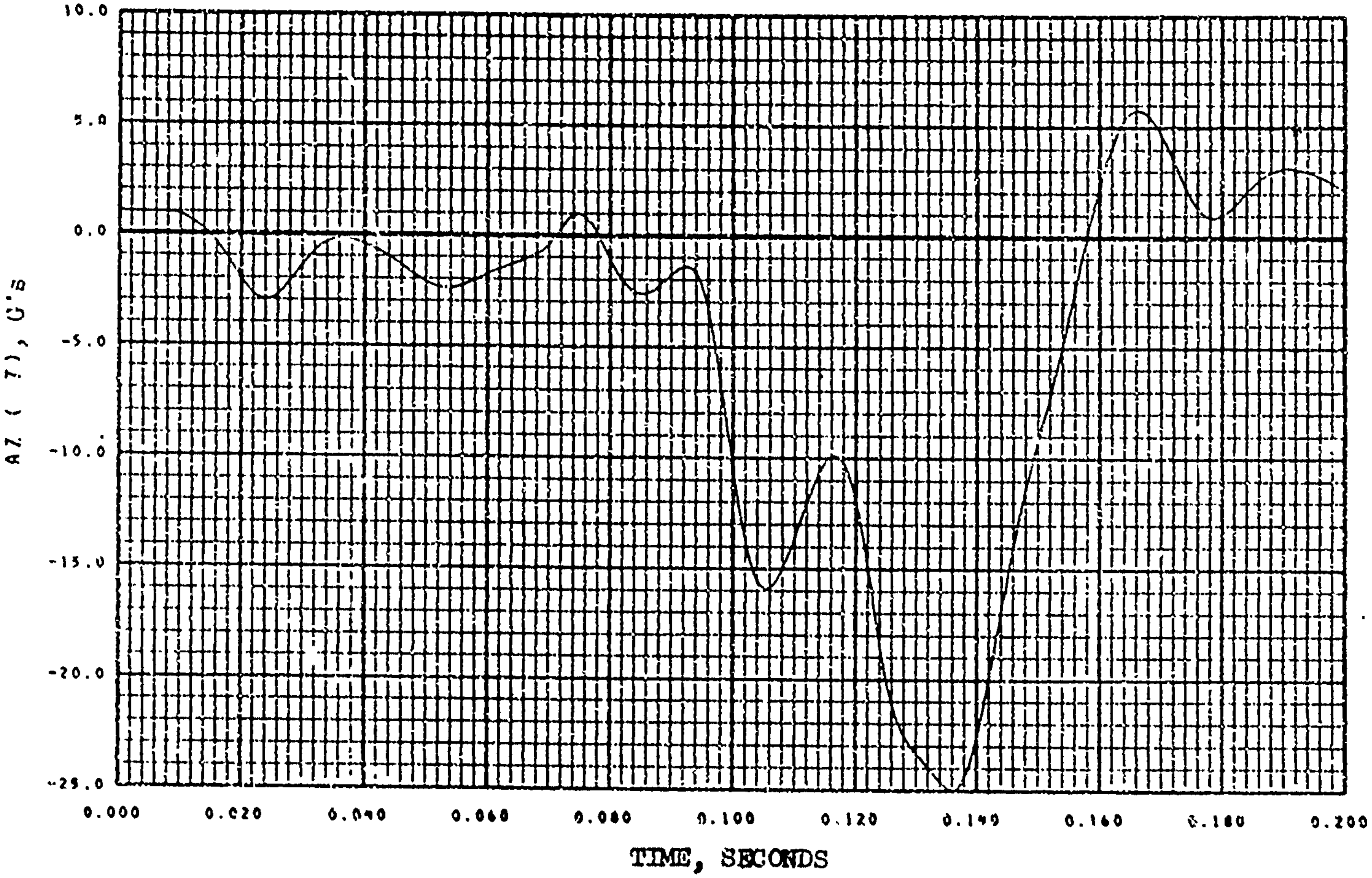


Figure 17. Sample Case, Engine Vertical Velocity Time History Plot.



RUN 31-52 DROP TEST CORRELATION 20G/18G ENGINE

Figure 18. Sample Case, Engine Vertical Acceleration Time History Plot.

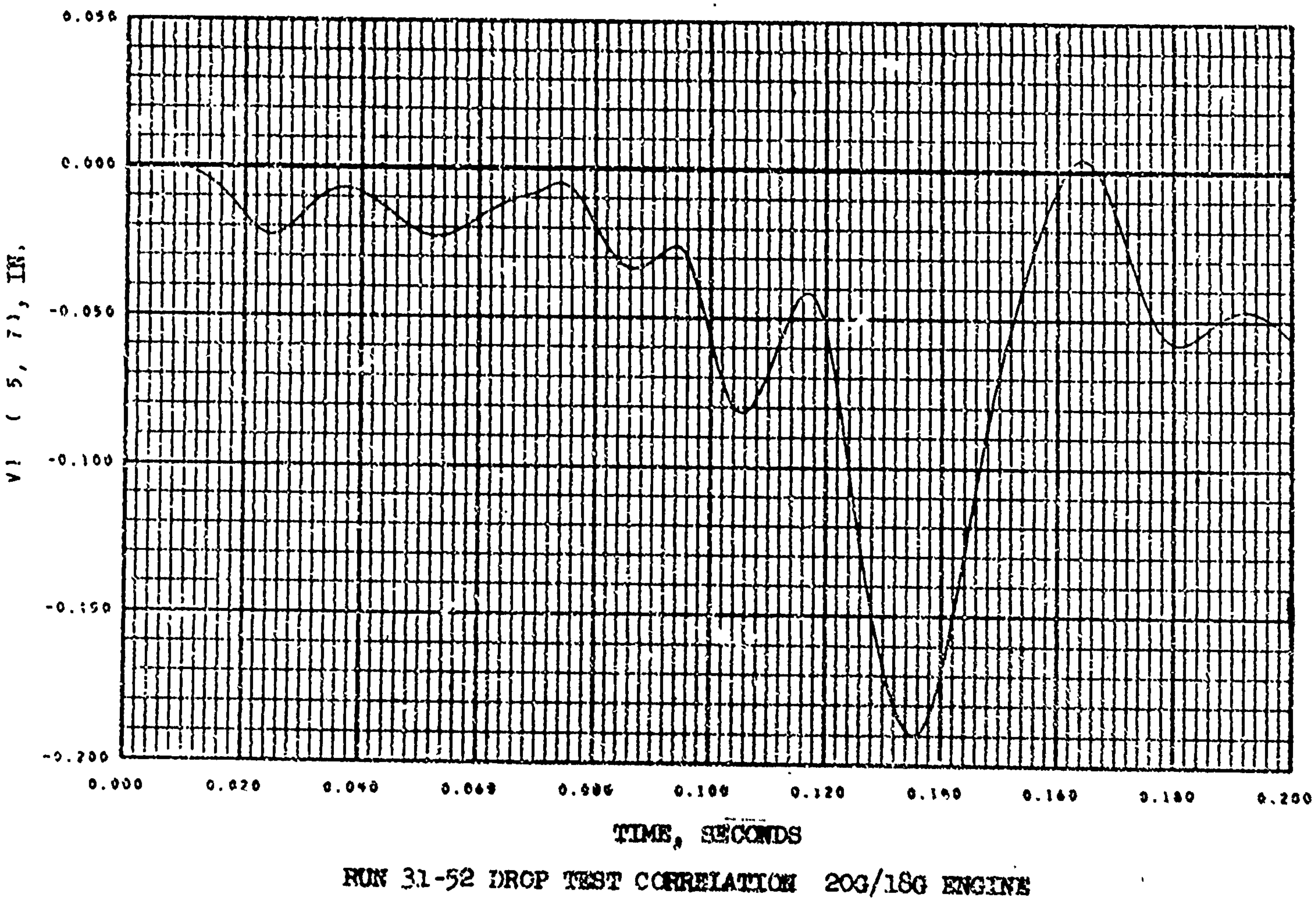


Figure 19. Sample Case, Engine Mount Vertical Deflection Time History Plot.

```
      IMPLICIT REAL*8 (A-H,O-Z)                                          CRS00010
      REAL*4 PLOT(30000),ZAR,TMPLOT(500)
      DIMENSION SC(40,3),ZAR(200),IPLOT(150),IDPLOT(150)
      DIMENSION IG(80),JG(80),PHIIJ(80),THEIJ(80),PSIIJ(80),WGT(40),     CRS00020
     1  XI(40),YI(40),ZI(40),XYI(40),YZI(40),XZI(40),HEX(40),HEY(40),   CRS00030
     2  HFZ(40),ALIFT(40),X(40),Y(40),Z(40),PHI(40),THETA(40),PSI(40),  CRS00040
     3  U(40),V(40),W(40),P(40),Q(40),R(40),XDOT(40),YDOT(40),ZDOT(40), CRS00050
     4  PHIDOT(40),THEDOT(40),PSIDOT(40),UDOT(40),VDOT(40),WDOT(40)      CRS00060
      DIMENSION AIJ(9),AI(9),AJ(9),AIDOT(9),DX(40),DY(40),DZ(40),        CRS00070
     1  DPHI(40),DTHETA(40),DPSI(40),D(6),DF(6),XX(40),XY(40),XZ(40),   CRS00080
     2  XL(40),XM(40),XN(40),DELI(40),XI1(40),XI2(40),XI3(40),          CRS00090
     3  XI4(40),XI5(40),XI6(40),XK(2880),FMBAR(2880),FMBAR3(6,6,80),    CRS00100
     4  FM(2880),XKRIN(10,6,80),VEE(480),VMAX(480),NN(40,3),NN2(40,3)   CRS00110
      DIMENSION XKI3(9,6,80),BIJ(360),CIJ(360),DIJ(720),XLBAR(40,3),     CRS00120
     1  XXLBAR(3),ISP(40,3),IISP(3),XMU(40,3),XKE(40,3),DAI(360),       CRS00130
     2  IBS(40,3),IBS2(40,3),SI(40,3),SF(40,3),FSPDF(40,3),PHIDP(40),   CRS00140
     3  THEDP(40),PSIDP(40),FSPBAR(40,3),FSPBA2(40,3),XLNGTH(3),XC(6),  CRS00150
     4  XDP(40),YDP(40),ZDP(40),FM3(6,6,80),VEE2(6,80),VEEDOT(3,3)      CRS00160
      DIMENSION PDOT(40),QDOT(40),RDOT(40),N(480),N3(80,6),DVSIGN(6),    CRS00170
     1  XKS(4320),XKS3(9,6,80),XKI(4320),TITLE(10)                       CRS00180
      DIMENSION XOLD(40),YOLD(40),ZOLD(40),PHIOLD(40),THEOLD(40),        CRS00190
     1  PSIOLD(40),POLD(40),QOLD(40),ROLD(40),UOLD(40),VOLD(40),WOLD(40)CRS00200
      DIMENSION XXK(80),XXJ(80),XYK(80),XYJ(80),XZK(80),XZJ(80),         CRS00210
     1  XLK(80),XLJ(80),XMK(80),XMJ(80),XNK(80),XNJ(80)                  CRS00220
      DIMENSION DXIJ(80),DYIJ(80),DZIJ(80)                               CRS00230
      DIMENSION PIN(40),QIN(40),RIN(40),PINO(40),QINO(40),RINO(40),      CRS00230
     1  DPIN(40),DQIN(40),DRIN(40)                                       CRS00240
      DIMENSION DD(6),DPX(40),DPY(40),DPZ(40),DPL(40),DPM(40),DPN(40)    CRS00250
      DIMENSION C(6,80),CBAR(80),DXDA(6,80)                              CRS00280
      DIMENSION XACC(40),YACC(40),ZACC(40)
      DIMENSION SUMDF(6,80),TRUPT(80),IRUPT(80),JRUPT(80)
       DIMENSION TPEN(80),IPEN(80)
      DIMENSION IJPR(76)
      DIMENSION AITAJ(9)
      DIMENSION FSPOI(40,3),SA(40,3),SB(40,3)
      DIMENSION DRI(76)
      COMMON DRI
      COMMON FSPOI,SA,SB
      COMMON AITAJ
      COMMON XNBAR,XPBAR,YNBAR,YPBAR,ZNBAR,ZPBAR,TPEN
      COMMON SUMDF,TRUPT,DXDA,SC
      COMMON XACC,YACC,ZACC
      COMMON C,CBAR                                                      CRS00290
      COMMON DD,DPX,DPY,DPZ,DPL,DPM,DPN                                  CRS00300
      COMMON PIN,QIN,RIN,PINO,QINO,RINO,DPIN,DQIN,DRIN                   CRS00320
      COMMON DXIJ,DYIJ,DZIJ,ZG                                           CRS00330
      COMMON XXK,XXJ,XYK,XYJ,XZK,XZJ,XLK,XLJ,XMK,XMJ,XNK,XNJ             CRS00340
      COMMON XOLD,YOLD,ZOLD,PHIOLD,THEOLD,PSIOLD,POLD,QOLD,ROLD,UOLD,    CRS00350
     1  VOLD,WOLD,DT2,DTHALF                                             CRS00360
      COMMON PHI,THETA,PSI                                               CRS00370
      COMMON BIJ,PSIDOT,THEDOT,PHIDOT,CIJ,X,Y,Z,XIJ,YIJ,ZIJ,D,DF         CRS00380
      COMMON AI,AIDOT,AJ,AIJ,DX,DY,DZ,DPHI,DTHETA,DPSI,DVSIGN            CRS00390
      COMMON                        VEE,FMBAR,FM,XKS,XKI,VMAX            CRS00400
      COMMON XX,XY,XZ,XL,XM,XN,WGT,ALIFT,XC,P,Q,R,U,V,W                  CRS00410
      COMMON UDOT,VDOT,WDOT,XZI,YZI,ZI,HFZ,XI,XYI,HEX,YI,HEY,DELI        CRS00420
      COMMON PDOT,XI1,XI2,XI3,QDOT,XI5,XI4,RDOT,XI6,XDOT,YDOT,ZDOT       CRS00430
      COMMON             XLBAR,SF,FSPDF,XKE,FSPBAR,XMU,VEEDOT            CRS00440
      COMMON XGDOT,YGDOT,ZGDOT,PPR,QPR,RPR,PHIPR,THEPR,PSIPR             CRS00360
      COMMON PHIDP,THEDP,PSIDP,XDP,YDP,ZDP,DAI,DELTAT,TMAX,TIME,TITLE    CRS00460
      COMMON PHIIJ,THEIJ,PSIIJ,XK,DIJ,XXLBAR,SI,XLNGTH,IP                CRS00470
```

Figure 20. Program Listing.

```
      COMMON NM,I,J,ILAST,ITABIJ,ITAB6,IJLIJ,IJKLIJ,IJKK,IJL,IG,JG,ITAB,CRS00480
     1 ITABD,IJKL,ITABL1,IPRINT,ITABLE,ILINES,NPR,IGS,IISP,ISP,IBS,N,NNCRS00490
      COMMON KRUPT,IRUPT,JRUPT
      COMMON INDP,IPEN,KPEN
      COMMON IJPR
      COMMON PLOT,ZAR,TMPLOT,IPLOT,IDPLOT,IPLSW,IPLC,JPLOT,NPLOT,ITPLOT
      EQUIVALENCE (XKS(1),XKS3(1,1,1)),(XKI(1),XKI3(1,1,1)),            CRS00410
     1 (XKRIN(1,1,1),FMBAR(1)),(FM(1),FM3(1,1,1)),(VEE(1),VEE2(1,1))    CRS00420
      EQUIVALENCE (FMBAR(1),FMBAR3(1,1,1)),(N(1),N3(1,1)),(NN(1,1),     CRS00430
     1 NN2(1,1)),(FSPBAR(1,1),FSPBA2(1,1)),(IBS(1,1),IBS2(1,1))         CRS00440
      IPLSW = [illegible]
      ITABD = [illegible]                                               CRS00530
      ITAB6 = 5*ITABD                                                   CRS00540
    1 CALL INPUT                                                        CRS00550
      IF(NM) 1000,1000,2                                                CRS00480
    2 DT2 = 2.0*DELTAT                                                  CRS00560
      DTHALF = .5*DELTAT                                                CRS00570
      ITABL1 = ITABLE-1                                                 CRS00600
      KRUPT = 0
      JPLOT = 0
      KPEN=0
C (26)                                                                  CRS00610
      DO 130 I = 1,NM                                                   CRS00620
      XI1(I) = YI(I)*ZI(I)-YZI(I)*YZI(I)                                CRS00630
      XI2(I) = XYI(I)*ZI(I)+XZI(I)*YZI(I)                               CRS00640
      XI3(I) = XYI(I)*YZI(I)+YI(I)*XZI(I)                               CRS00650
      XI4(I) = XI(I)*YZI(I)+XZI(I)*XYI(I)                               CRS00660
      XI5(I) = XI(I)*ZI(I)-XZI(I)*XZI(I)                                CRS00670
      XI6(I) = XI(I)*YI(I)-XYI(I)*XYI(I)                                CRS00680
  130 DELI(I) = 1.0/(XI(I)*XI1(I)-XYI(I)*XI2(I)-XZI(I)*XI3(I))          CRS00690
C COMPUTE SLOPES AND INTERCEPTS OF TABLE LINE SEGMENTS                  CRS00700
      CALL LINES                                                        CRS00710
C ZERO ARRAYS                                                           CRS00720
      TIME = 0.0                                                        CRS00730
      NM9 = 9*NM                                                        CRS00740
      DO 140 I = 1,NM9                                                  CRS00750
  140 BIJ(I) = 0.0                                                      CRS00760
      DO 150 I = 1,NM                                                   CRS00770
      DX(I) = 0.0                                                       CRS00780
      DY(I) = 0.0                                                       CRS00790
      DZ(I) = 0.0                                                       CRS00800
      DPHI(I) = 0.0                                                     CRS00810
      DTHETA(I) = 0.0                                                   CRS00820
      DPSI(I) = 0.0                                                     CRS00830
      XX(I) = 0.0                                                       CRS00840
      XY(I) = 0.0                                                       CRS00850
      XZ(I) = 0.0                                                       CRS00860
      XL(I) = 0.0                                                       CRS00870
      XM(I) = 0.0                                                       CRS00880
      XN(I) = 0.0                                                       CRS00890
      DPX(I) = 0.0                                                      CRS00900
      DPY(I) = 0.0                                                      CRS00910
      DPZ(I) = 0.0                                                      CRS00920
      DPL(I) = 0.0                                                      CRS00930
      DPM(I) = 0.0                                                      CRS00940
      DPN(I) = 0.0                                                      CRS00950
      DPIN(I) = 0.0                                                     CRS00960
      DOIN(I) = 0.0                                                     CRS00970
      DRIN(I) = 0.0                                                     CRS00980
      XACC(I)=0.0
```

Figure 20. (Continued)

```
      YACC(I)=0.0
      ZACC(I)=0.0
      DO 150 K = 1,3                                                    CRS00990
      IBS2(I,K) = 0                                                     CRS01000
      NV2(I,K) = 0                                                      CRS01010
      SC(I,K) = 0.0
  150 FSPBA2(I,K) = 0.0                                                 CRS01020
      DO 160 IJ = 1,IGS                                                 CRS01030
      XXK(IJ) = 0.0                                                     CRS01040
      XXJ(IJ) = 0.0                                                     CRS01050
      XYK(IJ) = 0.0                                                     CRS01060
      XYJ(IJ) = 0.0                                                     CRS01070
      XZK(IJ) = 0.0                                                     CRS01080
      XZJ(IJ) = 0.0                                                     CRS01090
      XLK(IJ) = 0.0                                                     CRS01100
      XLJ(IJ) = 0.0                                                     CRS01110
      XMK(IJ) = 0.0                                                     CRS01120
      XMJ(IJ) = 0.0                                                     CRS01130
      XNK(IJ) = 0.0                                                     CRS01140
      XNJ(IJ) = 0.0                                                     CRS01150
      DXIJ(IJ) = 0.0                                                    CRS01300
      DYIJ(IJ) = 0.0                                                    CRS01310
      DZIJ(IJ) = 0.0                                                    CRS01320
      DO 160 L = 1,6                                                    CRS01330
      SUMDF(L,IJ) = 0.0
      N3(IJ,L) = 0                                                      CRS01340
      VEE2(L,IJ) = 0.0                                                  CRS01350
      DO 160 K = 1,6                                                    CRS01360
      FM3(L,K,IJ) = 0.0                                                 CRS01370
  160 FMBAR3(L,K,IJ) = 0.0                                              CRS01380
      DO 165 J = 1,3                                                    CRS01390
      DO 165 K = 1,3                                                    CRS01400
  165 VEEDOT(J,K) = 0.0                                                 CRS01410
C DO INITIAL CONDITIONS                                                 CRS01420
      CALL IC                                                           CRS01430
C DO ALL THE (AIJ) INTO DIJ                                             CRS01440
      CALL DOAIJ                                                        CRS01450
      CALL DERIV                                                        CRS01470
      CALL PRINT                                                        CRS01500
      IPC = 0                                                           CRS01510
      IF(NPLOT.NE.0) CALL SAVE
      DO 200 I = 1,NM                                                   CRS01520
C PRESET OLD VALUES                                                     CRS01530
      PINO(I) = 0.0                                                     CRS01540
      QINO(I) = 0.0                                                     CRS01550
      RINO(I) = 0.0                                                     CRS01560
      XOLD(I) = X(I)                                                    CRS01570
      YOLD(I) = Y(I)                                                    CRS01580
      ZOLD(I) = Z(I)                                                    CRS01590
      PHIOLD(I) = PHI(I)                                                CRS01600
      THEOLD(I) = THETA(I)                                              CRS01610
      PSIOLD(I) = PSI(I)                                                CRS01620
      POLD(I) = P(I)                                                    CRS01630
      QOLD(I) = Q(I)                                                    CRS01640
      ROLD(I) = R(I)                                                    CRS01650
      UOLD(I) = U(I)                                                    CRS01660
      VOLD(I) = V(I)                                                    CRS01670
      WOLD(I) = W(I)                                                    CRS01680
C DO 1ST STEP EULER                                                     CRS01690
      DPIN(I) = DELTAT*P(I)                                             CRS01700
```

Figure 20. (Continued)

```
      DQIN(I) = DELTAT*Q(I)                                             CRS01710
      DRIN(I) = DELTAT*R(I)                                             CRS01720
      PIN(I) = DPIN(I)                                                  CRS01730
      QIN(I) = DQIN(I)                                                  CRS01740
      RIN(I) = DRIN(I)                                                  CRS01750
      P(I) = P(I)+DELTAT*PDOT(I)                                        CRS01760
      Q(I) = Q(I)+DELTAT*QDOT(I)                                        CRS01770
      R(I) = R(I)+DELTAT*RDOT(I)                                        CRS01780
      U(I) = U(I)+DELTAT*UDOT(I)                                        CRS01790
      V(I) = V(I)+DELTAT*VDOT(I)                                        CRS01800
      W(I) = W(I)+DELTAT*WDOT(I)                                        CRS01810
      DX(I) = DELTAT*XDOT(I)                                            CRS01820
      X(I) = X(I)+DX(I)                                                 CRS01830
      DY(I) = DELTAT*YDOT(I)                                            CRS01840
      Y(I) = Y(I)+DY(I)                                                 CRS01850
      DZ(I) = DELTAT*ZDOT(I)                                            CRS01860
      Z(I) = Z(I)+DZ(I)                                                 CRS01870
      DPHI(I) = DELTAT*PHIDOT(I)                                        CRS01880
      PHI(I) = PHI(I)+DPHI(I)                                           CRS01890
      DTHETA(I) = DELTAT*THEDOT(I)                                      CRS01900
      THETA(I) = THETA(I)+DTHETA(I)                                     CRS01910
      DPSI(I) = DELTAT*PSIDOT(I)                                        CRS01920
      PSI(I) = PSI(I)+DPSI(I)                                           CRS01930
  200 CONTINUE                                                          CRS01940
  190 TIME = TIME+DELTAT                                                CRS01950
      CALL DERIV                                                        CRS02020
      IPC = IPC+1                                                       CRS02030
      IF(IPC-IPRINT) 310,270,270                                        CRS02040
  270 CALL PRINT                                                        CRS02050
      IPC = 0                                                           CRS02060
  310 IF(NPLOT.EQ.0) GO TO 280
      IPLC = IPLC+1
      IF(IPLC.EQ.ITPLOT) CALL SAVE
C PREDICT, MOVE DOWN, AND DO DELTA'S                                     CRS02070
  280 DO 300 I = 1,NM                                                   CRS02080
      T = PINO(I)+DT2*P(I)                                              CRS02090
      PINO(I) = PIN(I)                                                  CRS02100
      PIN(I) = T                                                        CRS02110
      DPIN(I) = PIN(I)-PINO(I)                                          CRS02120
      T = QINO(I)+DT2*Q(I)                                              CRS02130
      QINO(I) = QIN(I)                                                  CRS02140
      QIN(I) = T                                                        CRS02150
      DQIN(I) = QIN(I)-QINO(I)                                          CRS02160
      T = RINO(I)+DT2*R(I)                                              CRS02170
      RINO(I) = RIN(I)                                                  CRS02180
      RIN(I) = T                                                        CRS02190
      DRIN(I) = RIN(I)-RINO(I)                                          CRS02200
      T = XOLD(I)+DT2*XDOT(I)                                           CRS02210
      XOLD(I) = X(I)                                                    CRS02220
      X(I) = T                                                          CRS02230
      DX(I) = X(I)-XOLD(I)                                              CRS02240
      T = YOLD(I)+DT2*YDOT(I)                                           CRS02250
      YOLD(I) = Y(I)                                                    CRS02260
      Y(I) = T                                                          CRS02270
      DY(I) = Y(I)-YOLD(I)                                              CRS02280
      T = ZOLD(I)+DT2*ZDOT(I)                                           CRS02290
      ZOLD(I) = Z(I)                                                    CRS02300
      Z(I) = T                                                          CRS02310
      DZ(I) = Z(I)-ZOLD(I)                                              CRS02320
      T = PHIOLD(I)+DT2*PHIDOT(I)                                       CRS02330
```

Figure 20. (Continued)

```
      PHIOLD(I) = PHI(I)                                                CRS02340
      PHI(I) = T                                                        CRS02350
      DPHI(I) = PHI(I)-PHIOLD(I)                                        CRS02360
      T = THEOLD(I)+DT2*THEDOT(I)                                       CRS02370
      THEOLD(I) = THETA(I)                                              CRS02380
      THETA(I) = T                                                      CRS02390
      DTHETA(I) = THETA(I)-THEOLD(I)                                    CRS02400
      T = PSIOLD(I)+DT2*PSIDOT(I)                                       CRS02410
      PSIOLD(I) = PSI(I)                                                CRS02420
      PSI(I) = T                                                        CRS02430
      DPSI(I) = PSI(I)-PSIOLD(I)                                        CRS02440
      T = POLD(I)+DT2*PDOT(I)                                           CRS02450
      POLD(I) = P(I)                                                    CRS02460
      P(I) = T                                                          CRS02470
      T = QOLD(I)+DT2*QDOT(I)                                           CRS02480
      QOLD(I) = Q(I)                                                    CRS02490
      Q(I) = T                                                          CRS02500
      T = ROLD(I)+DT2*RDOT(I)                                           CRS02510
      ROLD(I) = R(I)                                                    CRS02520
      R(I) = T                                                          CRS02530
      T = UOLD(I)+DT2*UDOT(I)                                           CRS02540
      UOLD(I) = U(I)                                                    CRS02550
      U(I) = T                                                          CRS02560
      T = VOLD(I)+DT2*VDOT(I)                                           CRS02570
      VOLD(I) = V(I)                                                    CRS02580
      V(I) = T                                                          CRS02590
      T = WOLD(I)+DT2*WDOT(I)                                           CRS02600
      WOLD(I) = W(I)                                                    CRS02610
      W(I) = T                                                          CRS02620
  300 CONTINUE                                                          CRS02630
      IF(TIME-TMAX) 190,190,500                                         CRS02640
  500 IF (KRUPT) 5500,5500,5000
 5000 PRINT 2000
 2000 FORMAT(1H1,7X,15HRUPTURE SUMMARY,/)
      PRINT 3000
 3000 FORMAT(1H ,9X,1HI,9X,1HJ,7X,4HTIME,/)
      PRINT 4000,(IRUPT(KRT),JRUPT(KRT),TRUPT(KRT),KRT=1,KRUPT)
 4000 FORMAT(1H ,2I10,F10.5)
 5500 IF (KPEN.LE.0)  GO TO 6000
      PRINT 5501
 5501 FORMAT(1H1,7X,'CONTROL VOLUME PENETRATIONS' //)
      PRINT 5502
 5502 FORMAT(1H ,13X,'TIME',10X,'MASS' /)
      PRINT 5503,(TPEN(K),IPEN(K),K=1,KPEN)
 5503 FORMAT(1H ,10X,F10.5,I10)
 6000 IF(NPLOT.NE.0) CALL TOLP
      GO TO 1
 1000 IF(IPLSW.NE.0) CALL EXITG(ZAR)
      STOP
      END                                                               CRS02650
```

Figure 20. (Continued)

```
      SUBROUTINE DERIV                                                  CRS02660
      IMPLICIT REAL*8 (A-H,O-Z)
      REAL*4 PLOT(30000),ZAP,TMPLOT(500)
      DIMENSION SC(40,3),ZAR(200),IPLOT(150),IDPLOT(150)
      DIMENSION IG(80),JG(80),PHIIJ(80),THEIJ(80),PSIIJ(80),WGT(40),    CRS02140
     1 XI(40),YI(40),ZI(40),XYI(40),YZI(40),XZI(40),HEX(40),HEY(40),    CRS02150
     2 HEZ(40),ALIFT(40),X(40),Y(40),Z(40),PHI(40),THETA(40),PSI(40),   CRS02160
     3 U(40),V(40),W(40),P(40),Q(40),R(40),XDOT(40),YDOT(40),ZDOT(40),  CRS02170
     4 PHIDOT(40),THEDOT(40),PSIDOT(40),UDOT(40),VDOT(40),WDOT(40)      CRS02180
      DIMENSION AIJ(9),AI(9),AJ(9),AIDOT(9),DX(40),DY(40),DZ(40),       CRS02190
     1 DPHI(40),DTHETA(40),DPSI(40),D(6),DF(6),XX(40),XY(40),XZ(40),    CRS02200
     2 XL(40),XM(40),XN(40),DELI(40),XI1(40),XI2(40),XI3(40),           CRS02210
     3 XI4(40),XI5(40),XI6(40),XK(2880),FMBAR(2880),FMBAR3(6,6,80),     CRS02220
     4 FM(2880),XKRIN(10,6,80),VEE(480),VMAX(480),NN(40,3),NN2(40,3)    CRS02230
      DIMENSION XKI3(9,6,80),BIJ(360),CIJ(360),DIJ(720),XLBAR(40,3),    CRS02240
     1 XXLBAR(3),ISP(40,3),IISP(3),XMU(40,3),XKE(40,3),DAI(360),        CRS02250
     2 IBS(40,3),IBS2(40,3),SI(40,3),SF(40,3),FSPOF(40,3),PHIDP(40),    CRS02260
     3 THEDP(40),PSIDP(40),FSPBAR(40,3),FSPBAZ(40,3),XLNGTH(3),XC(6),   CRS02270
     4 XDP(40),YDP(40),ZDP(40),FM3(6,6,80),VEE2(6,80),VEEDOT(3,3)       CRS02280
      DIMENSION PDOT(40),QDOT(40),RDOT(40),N(480),N3(80,6),DVSIGN(6),   CRS02290
     1 XKS(4320),XKS3(9,6,80),XKI(4320),TITLE(10)                       CRS00180
      DIMENSION AIAIJT(9),DAI(9)                                        CRS02310
      DIMENSION XOLD(40),YOLD(40),ZOLD(40),PHIOLD(40),THEOLD(40),       CRS02320
     1 PSIOLD(40),POLD(40),QOLD(40),ROLD(40),UOLD(40),VOLD(40),WOLD(40)CRS02330
      DIMENSION XXK(80),XXJ(80),XYK(80),XYJ(80),XZK(80),XZJ(80),        CRS02340
     1 XLK(80),XLJ(80),XMK(80),XMJ(80),XNK(80),XNJ(80)                  CRS02350
      DIMENSION DXIJ(80),DYIJ(80),DZIJ(80)                              CRS02360
      DIMENSION PIN(40),QIN(40),RIN(40),PINO(40),QINO(40),RINO(40),     CRS00230
     1 DPIN(40),DQIN(40),DRIN(40)                                       CRS00240
      DIMENSION SINCOS(6)                                               CRS02920
      DIMENSION AITAJ(9)                                                CRS02930
      DIMENSION DD(6),DPX(40),DPY(40),DPZ(40),DPL(40),DPM(40),DPN(40)   CRS00250
      DIMENSION C(6,80),CBAR(80),DXDA(6,80)                             CRS00280
      DIMENSION XACC(40),YACC(40),ZACC(40)
      DIMENSION XX3(6,5,20)
      DIMENSION SUMDF(6,80),TRUPT(80),IRUPT(80),JRUPT(80),IRJPSW(80)
      DIMENSION IPENSW(80),AP(9)
      DIMENSION TPEN(80),IPEN(80)
      DIMENSION ISPR(76)
      DIMENSION FSPOI(40,3),SA(40,3),SB(40,3)
      DIMENSION DRI(76)
      COMMON DRI
      COMMON FSPOI,SA,SB
      COMMON AITAJ
      COMMON XNBAR,XPBAR,YNBAR,YPBAR,ZNBAR,ZPBAR,TPEN
      COMMON SUMDF,TRUPT,DXDA,SC
      COMMON XACC,YACC,ZACC
      COMMON C,CBAR                                                     CRS02980
      COMMON DD,DPX,DPY,DPZ,DPL,DPM,DPN                                 CRS00300
      COMMON PIN,QIN,RIN,PINO,QINO,RINO,DPIN,DQIN,DRIN                  CRS03010
      COMMON DXIJ,DYIJ,DZIJ,ZG                                          CRS03020
      COMMON XXK,XXJ,XYK,XYJ,XZK,XZJ,XLK,XLJ,XMK,XMJ,XNK,XNJ            CRS03030
      COMMON XOLD,YOLD,ZOLD,PHIOLD,THEOLD,PSIOLD,POLD,QOLD,ROLD,UOLD,   CRS03040
     1 VOLD,WOLD,DT2,DTHALF                                             CRS03050
      COMMON PHI,THETA,PSI                                              CRS03060
      COMMON BIJ,PSIDOT,THEDOT,PHIDOT,CIJ,X,Y,Z,XIJ,YIJ,ZIJ,D,DF        CRS03070
      COMMON AI,AIDOT,AJ,AIJ,DX,DY,DZ,DPHI,DTHETA,DPSI,DVSIGN           CRS03080
      COMMON                  VEE,FMBAR,FM,XKS,XKI,VMAX                 CRS00400
      COMMON XX,XY,XZ,XL,XM,XN,WGT,ALIFT,XC,P,Q,R,U,V,W                 CRS03100
      COMMON UDOT,VDOT,WDOT,XZI,YZI,ZI,HEZ,XI,XYI,HEX,YI,HEY,DELI       CRS03110
```

Figure 20. (Continued)

```
      COMMON PDOT,XI1,XI2,XI3,QDOT,XI5,XI4,RDOT,XI6,XDOT,YDOT,ZDOT       CRS03120
      COMMON         XLBAR,SF,FSPOF,XKE,FSPBAR,XMU,VEEDOT                CRS00440
      COMMON XGDOT,YGDOT,ZGDOT,PPR,QPR,RPR,PHIPR,THEPR,PSIPR             CRS00360
      COMMON PHIDP,THEDP,PSIDP,XDP,YDP,ZDP,OAI,DELTAT,TMAX,TIME,TITLE    CRS03150
      COMMON PHIIJ,THEIJ,PSIIJ,XK,DIJ,XXLBAR,SI,XLNGTH,IP                CRS00470
      COMMON NM,I,J,ILAST,ITABIJ,ITAB6,IJLIJ,IJKLIJ,IJKK,IJL,IG,JG,ITAB8,CRS03170
     1  ITABD,IJKL,ITABL1,IPRINT,ITABLE,ILINES,NPR,IGS,IISP,ISP,IBS,N,NNCRS00490
      COMMON KRUPT,IRUPT,JRUPT
      COMMON INDP,IPEN,KPEN
      COMMON IJPR
      COMMON PLOT,ZAR,TMPLOT,IPLOT,IDPLOT,IPLSW,IPLC,JPLOT,NPLOT,ITPLOT
      EQUIVALENCE (XKS(1),XKS3(1,1,1)),(XKI(1),XKI3(1,1,1)),             CRS02540
     1  (XKRIN(1,1,1),FMBAR(1)),(FM(1),FM3(1,1,1)),(VEE(1),VEE2(1,1))    CRS02550
      EQUIVALENCE (FMBAR(1),FMBAR3(1,1,1)),(N(1),N3(1,1)),(NN(1,1),      CRS02560
     1  NN2(1,1)),(FSPBAR(1,1),FSPBA2(1,1)),(IBS(1,1),IBS2(1,1))         CRS02570
      EQUIVALENCE (XK3(1,1,1),XK(1))
      EQUIVALENCE (S1,SINCOS(1)),(C1,SINCOS(2)),(S2,SINCOS(3))           CRS03220
      EQUIVALENCE (C2,SINCOS(4)),(S3,SINCOS(5)),(C3,SINCOS(6))           CRS03230
      SIN(X) = DSIN(X)                                                   CRS02580
      COS(X) = DCOS(X)                                                   CRS02590
      TT = .200
      ET = .800
      IF(TIME.NE.0.0) GO TO 60
      DO 70 IJ = 1,IGS
   70 IRUPSW(IJ) = 0
      DO 72 I=1,NM
   72 IPENSW(I)=0
C DO ALL THE (AI)((AJ))                                                  CRS03600
   60 DO 10 I = 1,NM                                                     CRS03610
      ARG = PHI(I)                                                       CRS03620
      S1 = SIN(ARG)                                                      CRS03630
      C1 = COS(ARG)                                                      CRS03640
      ARG = THETA(I)                                                     CRS03650
      S2 = SIN(ARG)                                                      CRS03660
      C2 = COS(ARG)                                                      CRS03670
      ARG = PSI(I)                                                       CRS03680
      S3 = SIN(ARG)                                                      CRS03690
      C3 = COS(ARG)                                                      CRS03700
      DO 40 J = 1,6                                                      CRS03710
      T = SINCOS(J)                                                      CRS03720
      IF(T) 45,40,50                                                     CRS03730
   45 T = -T                                                             CRS03740
   50 IF(T-1.E-10) 55,40,40                                              CRS03750
   55 SINCOS(J) = 0.0                                                    CRS03760
   40 CONTINUE                                                           CRS03770
C                                                                        CRS03780
      J = 9*(I-1)                                                        CRS03790
C MOVE AI S TO OLD AI S                                                  CRS03800
      DO 4 JJ = 1,9                                                      CRS03810
    4 OAI(J+JJ) = BIJ(J+JJ)                                              CRS03820
      S1S2 = S1*S2                                                       CRS03830
      C1S2 = C1*S2                                                       CRS03840
      AI(1) = C2*C3                                                      CRS03850
      BIJ(J+1) = AI(1)                                                   CRS03860
      AI(2) = C2*S3                                                      CRS03870
      BIJ(J+2) = AI(2)                                                   CRS03880
      AI(3) = -S2                                                        CRS03890
      BIJ(J+3) = AI(3)                                                   CRS03900
      AI(4) = -C1*S3+S1S2*C3                                             CRS03910
      BIJ(J+4) = AI(4)                                                   CRS03920
```

Figure 20. (Continued)

```
      AI(5) = C1*C3+S1S2*S3                                             CRS03930
      BIJ(J+5) = AI(5)                                                  CRS03940
      AI(6) = S1*C2                                                     CRS03950
      BIJ(J+6) = AI(6)                                                  CRS03960
      AI(7) = S1*S3+C1S2*C3                                             CRS03970
      BIJ(J+7) = AI(7)                                                  CRS03980
      AI(8) = -S1*C3+C1S2*S3                                            CRS03990
      BIJ(J+8) = AI(8)                                                  CRS04000
      AI(9) = C1*C2                                                     CRS04010
      BIJ(J+9) = AI(9)                                                  CRS04020
C (27)                                                                  CRS04030
      PP = P(I)                                                         CRS04040
      QQ = Q(I)                                                         CRS04050
      RR = R(I)                                                         CRS04060
      UU = U(I)                                                         CRS04070
      VV = V(I)                                                         CRS04080
      WW = W(I)                                                         CRS04090
      XDOTI = XDOT(I)                                                   CRS04100
      XDOT(I) = AI(1)*UU+AI(4)*VV+AI(7)*WW                              CRS04110
      YDOTI = YDOT(I)                                                   CRS04120
      YDOT(I) = AI(2)*UU+AI(5)*VV+AI(8)*WW                              CRS04130
      ZDOTI = ZDOT(I)                                                   CRS04140
      ZDOT(I) = AI(3)*UU+AI(6)*VV+AI(9)*WW                              CRS04150
C (28),(29)                                                             CRS04160
      CS = S1/C2                                                        CRS04170
      CC = C1/C2                                                        CRS04180
      PHDOTI = PHIDOT(I)                                                CRS04190
      PHIDOT(I) = PP+QQ*CS*S2+RR*CC*S2                                  CRS04200
      THDOTI = THEDOT(I)                                                CRS04210
      THEDOT(I) = QQ*C1-RR*S1                                           CRS04220
      PSDOTI = PSIDOT(I)                                                CRS04230
      PSIDOT(I) = QQ*CS+RR*CC                                           CRS04240
C DO AIDOT NOW                                                          CRS04250
      T = PSIDOT(I)*C2                                                  CRS04260
      T1 = THEDOT(I)*S1-T*C1                                            CRS04270
      T2 = THEDOT(I)*C1+T*S1                                            CRS04280
      T3 = PHIDOT(I)-PSIDOT(I)*S2                                       CRS04290
      CIJ(J+1)= -BIJ(J+4)*T1-BIJ(J+7)*T2                                CRS04300
      CIJ(J+4)=  BIJ(J+1)*T1+BIJ(J+7)*T3                                CRS04310
      CIJ(J+7)=  BIJ(J+1)*T2-BIJ(J+4)*T3                                CRS04320
      CIJ(J+2)= -BIJ(J+5)*T1-BIJ(J+8)*T2                                CRS04330
      CIJ(J+5)=  BIJ(J+2)*T1+BIJ(J+8)*T3                                CRS04340
      CIJ(J+8)=  BIJ(J+2)*T2-BIJ(J+5)*T3                                CRS04350
      CIJ(J+3)= -BIJ(J+6)*T1-BIJ(J+9)*T2                                CRS04360
      CIJ(J+6)=  BIJ(J+3)*T1+BIJ(J+9)*T3                                CRS04370
      CIJ(J+9)=  BIJ(J+3)*T2-BIJ(J+6)*T3                                CRS04380
      IF(TIME) 10,10,5                                                  CRS04390
C CORRECT X,Y,Z,PHI,THEYA,PSI,                                          CRS04400
    5 X(I) = TT*X(I)+ET*(XOLD(I)+DTHALF*(XDOT(I)+XDOTI))                CRS03340
      Y(I) = TT*Y(I)+ET*(YOLD(I)+DTHALF*(YDOT(I)+YDOTI))                CRS03350
      Z(I) = TT*Z(I)+ET*(ZOLD(I)+DTHALF*(ZDOT(I)+ZDOTI))                CRS03360
      PHI(I) = TT*PHI(I)+ET*(PHIOLD(I)+DTHALF*(PHIDOT(I)+PHDOTI))       CRS03370
      THETA(I) = TT*THETA(I)+ET*(THEOLD(I)+DTHALF*(THEDOT(I)+THDOTI))   CRS03380
      PSI(I) = TT*PSI(I)+ET*(PSIOLD(I)+DTHALF*(PSIDOT(I)+PSDOTI))       CRS03390
C CLEAR THE DAMPING TERMS.
      DPX(I) = 0.0
      DPY(I) = 0.0
      DPZ(I) = 0.0
      DPL(I) = 0.0
      DPM(I) = 0.0
```

Figure 20. (Continued)

```
      DPN(I) = 0.0
   10 CONTINUE                                                          CRS04520
C DO 1000 IS MAIN DO LOOP  TO GET TOTAL INTERNAL FORCES AND MOMENTS     CRS04530
      ILAST = 0                                                         CRS04540
      ITABIJ = -ITAB6                                                   CRS04550
      IJLIJ = 0                                                         CRS04560
      IJKLIJ = -36                                                      CRS04570
      DO 1000 IJ = 1,IGS                                                CRS04580
      IJKLIJ = IJKLIJ+36                                                CRS04590
      IJKK = IJKLIJ-3                                                   CRS04600
      IJLIJ = IJLIJ+6                                                   CRS04610
      IJL = IJLIJ                                                       CRS04620
      ITABIJ = ITABIJ+ITAB6                                             CRS04630
      IF(IRUPSW(IJ).NE.0) GO TO 1000
      I = IG(IJ)                                                        CRS04640
      J = JG(IJ)                                                        CRS04660
C IF WE GET TO A NEW I WE MUST MOVE (AI) INTO AI AND (AIDOT) INTO AIDOT CRS04670
      IF(I-ILAST) 20,30,20                                              CRS04680
   20 ILAST = I                                                         CRS04690
      IS = 9*(I-1)                                                      CRS04700
      DO 320 KS = 1,9                                                   CRS04710
      IS = IS+1                                                         CRS04720
      AIDOT(KS) = CIJ(IS)                                               CRS04730
      DAI(KS) = DAI(IS)-BIJ(IS)                                         CRS04740
  320 AI(KS) = BIJ(IS)                                                  CRS04750
   30 XIJ = X(J)-X(I)                                                   CRS04800
      YIJ = Y(J)-Y(I)                                                   CRS04810
      ZIJ = Z(J)-Z(I)                                                   CRS04820
      XIJO = DXIJ(IJ)                                                   CRS04830
      YIJO = DYIJ(IJ)                                                   CRS04840
      ZIJO = DZIJ(IJ)                                                   CRS04850
      DXIJ(IJ) = XIJ                                                    CRS04860
      DYIJ(IJ) = YIJ                                                    CRS04870
      DZIJ(IJ) = ZIJ                                                    CRS04880
C                                                                       CRS04890
      IS = 9*(J-1)                                                      CRS04900
      IJS = 9*(IJ-1)                                                    CRS04910
      DO 310 KS = 1,9                                                   CRS04920
      IS = IS+1                                                         CRS04930
      IJS = IJS+1                                                       CRS04940
      AIJ(KS) = DIJ(IJS)                                                CRS04950
  310 AJ(KS) = BIJ(IS)                                                  CRS04960
C (4)                                                                   CRS04970
      T1 = DX(J)-DX(I)                                                  CRS04980
      T2 = DY(J)-DY(I)                                                  CRS04990
      T3 = DZ(J)-DZ(I)                                                  CRS05000
C (5)                                                                   CRS05010
      T4= AI(1)*T1+AI(2)*T2+AI(3)*T3-DAI(1)*XIJO-DAI(2)*YIJO-DAI(3)*ZIJOCRS05020
      T5= AI(4)*T1+AI(5)*T2+AI(6)*T3-DAI(4)*XIJO-DAI(5)*YIJO-DAI(6)*ZIJOCRS05030
      T6= AI(7)*T1+AI(8)*T2+AI(9)*T3-DAI(7)*XIJO-DAI(8)*YIJO-DAI(9)*ZIJOCRS05040
      D(1) = AIJ(1)*T4+AIJ(2)*T5+AIJ(3)*T6                              CRS05050
      D(2) = AIJ(4)*T4+AIJ(5)*T5+AIJ(6)*T6                              CRS05060
      D(3) = AIJ(7)*T4+AIJ(8)*T5+AIJ(9)*T6                              CRS05070
C (9)                                                                   CRS05150
      AITAJ(1) = AI(1)*AJ(1)+AI(2)*AJ(2)+AI(3)*AJ(3)                    CRS05160
      AITAJ(2) = AI(4)*AJ(1)+AI(5)*AJ(2)+AI(6)*AJ(3)                    CRS05170
      AITAJ(3) = AI(7)*AJ(1)+AI(8)*AJ(2)+AI(9)*AJ(3)                    CRS05180
      AITAJ(4) = AI(1)*AJ(4)+AI(2)*AJ(5)+AI(3)*AJ(6)                    CRS05190
      AITAJ(5) = AI(4)*AJ(4)+AI(5)*AJ(5)+AI(6)*AJ(6)                    CRS05200
      AITAJ(6) = AI(7)*AJ(4)+AI(8)*AJ(5)+AI(9)*AJ(6)                    CRS05210
```

Figure 20. (Continued)

```
      AITAJ(7) = AI(1)*AJ(7)+AI(2)*AJ(8)+AI(3)*AJ(9)                    CRS05220
      AITAJ(8) = AI(4)*AJ(7)+AI(5)*AJ(8)+AI(6)*AJ(9)                    CRS05230
      AITAJ(9) = AI(7)*AJ(7)+AI(8)*AJ(8)+AI(9)*AJ(9)                    CRS05240
      T1 = DPIN(J)                                                      CRS05250
      T2 = DQIN(J)                                                      CRS05260
      T3 = DRIN(J)                                                      CRS05270
      T4 = T1*AITAJ(1)+T2*AITAJ(4)+T3*AITAJ(7)-DPIN(I)                  CRS05280
      T5 = T1*AITAJ(2)+T2*AITAJ(5)+T3*AITAJ(8)-DQIN(I)                  CRS05290
      T6 = T1*AITAJ(3)+T2*AITAJ(6)+T3*AITAJ(9)-DRIN(I)                  CRS05300
C (9R)                                                                  CRS05310
      D(4) = AIJ(1)*T4+AIJ(2)*T5+AIJ(3)*T6                              CRS05320
      D(5) = AIJ(4)*T4+AIJ(5)*T5+AIJ(6)*T6                              CRS05330
      D(6) = AIJ(7)*T4+AIJ(8)*T5+AIJ(9)*T6                              CRS05340
      T1 = U(J)                                                         CRS05390
      T2 = V(J)                                                         CRS05400
      T3 = W(J)                                                         CRS05410
      T4 = T1*AITAJ(1)+T2*AITAJ(4)+T3*AITAJ(7)-U(I)                     CRS05420
      T5 = T1*AITAJ(2)+T2*AITAJ(5)+T3*AITAJ(8)-V(I)                     CRS05430
      T6 = T1*AITAJ(3)+T2*AITAJ(6)+T3*AITAJ(9)-W(I)                     CRS05440
      DD(1) = T4*AIJ(1)+T5*AIJ(2)+T6*AIJ(3)                             CRS05450
      DD(2) = T4*AIJ(4)+T5*AIJ(5)+T6*AIJ(6)                             CRS05460
      DD(3) = T4*AIJ(7)+T5*AIJ(8)+T6*AIJ(9)                             CRS05470
      T1 = P(J)                                                         CRS05480
      T2 = Q(J)                                                         CRS05490
      T3 = R(J)                                                         CRS05500
      T4 = T1*AITAJ(1)+T2*AITAJ(4)+T3*AITAJ(7)-P(I)                     CRS05510
      T5 = T1*AITAJ(2)+T2*AITAJ(5)+T3*AITAJ(8)-Q(I)                     CRS05520
      T6 = T1*AITAJ(3)+T2*AITAJ(6)+T3*AITAJ(9)-R(I)                     CRS05530
      DD(4) = T4*AIJ(1)+T5*AIJ(2)+T6*AIJ(3)                             CRS05540
      DD(5) = T4*AIJ(4)+T5*AIJ(5)+T6*AIJ(6)                             CRS05550
      DD(6) = T4*AIJ(7)+T5*AIJ(8)+T6*AIJ(9)                             CRS05560
      DO 270 K = 1,6                                                    CRS05570
  270 DD(K) = C(K,IJ)*DD(K)
C FORM VECTOR OF (+,-)1.0 TO USE IN ABS(VPIJL)                          CRS05590
      DO 360 K = 1,6                                                    CRS05600
      IF(D(K)) 370,380,380                                              CRS05610
  370 DVSIGN(K) = -1.0                                                  CRS05620
      GO TO 360                                                         CRS05630
  380 DVSIGN(K) = 1.0                                                   CRS05640
  360 CONTINUE                                                          CRS05650
      DO 150 K = 1,6                                                    CRS05660
      ITAB = ITABIJ-ITABD                                               CRS05670
      IJKK = IJKK+6                                                     CRS05680
      IJKL = IJKK                                                       CRS05690
      IJL = IJL-6                                                       CRS05700
      DF(K) = 0.0                                                       CRS05710
      DO 150 L = 1,6                                                    CRS05740
      ITAB = ITAB+ITABD                                                 CRS05750
      IJKL = IJKL+1                                                     CRS05760
      IJL = IJL+1                                                       CRS05770
      T = XK(IJKL)                                                      CRS05810
      IF(T) 160,150,160                                                 CRS05820
C THIS GETS ABS(VP(IJL))                                                CRS05830
  160 VP = DVSIGN(L)*(VEE(IJL)-FMBAR(IJKL))                             CRS05840
      IF(VP) 170,210,210                                                CRS05890
C SIGNS NOT SAME                                                        CRS05900
  170 IF(V(IJL)) 180,180,190                                            CRS05910
  180 M(IJL) = 1                                                        CRS05920
      FMBAR(IJKL) = VEE(IJL)-FM(IJKL)/T                                 CRS05930
  190 DELFM = T*D(L)                                                    CRS05980
```

Figure 20. (Continued)

```
      GO TO 220                                                 CRS05990
C SIGNS THE SAME                                                CRS06000
  210 N(IJL) = 0                                                CRS06010
      II = (VP+DXDA(L,IJ))/DXDA(L,IJ)                           CRS06020
C CLAMP II BETWEEN 1 AND ITABLE-1                               CRS06030
      IF(II-1) 211,215,213                                      CRS06040
  211 II = 1                                                    CRS06050
      GO TO 215                                                 CRS06060
  213 IF(II-ITABL1) 215,215,214                                 CRS06070
  214 II = ITABL1                                               CRS06080
  215 II = II+ITAB                                              CRS06090
      DELFN = (XKS(II)*VP+XKE(II))*T*D(L)                       CRS06100
  220 FN(IJKL) = FN(IJKL)+DELFN                                 CRS06150
      DF(K) = DF(K)+DELFN                                       CRS06160
  150 CONTINUE                                                  CRS06200
      DO 630 K = 1,6
  630 SUMDF(K,IJ) = SUMDF(K,IJ)+DF(K)
      IJL = IJL-6                                               CRS06210
      DO 230 L = 1,6                                            CRS06320
      IJL = IJL+1                                               CRS06230
      T = VEE(IJL)+D(L)                                         CRS06240
      VEE(IJL) = T                                              CRS06250
C MOVE DF TO D FOR (13) ETC.                                    CRS06260
      D(L) = DF(L)                                              CRS06270
      IF(T) 240,250,250                                         CRS06280
  240 T = -T                                                    CRS06290
  250 IF(T-VMAX(IJL)) 230,260,260                               CRS06300
  260 IRUPSW(IJ) = 1
      XX(I) = XX(I)-DXK(IJ)                                     CRS06320
      XY(I) = XY(I)-DYK(IJ)                                     CRS06330
      XZ(I) = XZ(I)-DZK(IJ)                                     CRS06340
      XL(I) = XL(I)-DLK(IJ)                                     CRS06350
      XM(I) = XM(I)-DMK(IJ)                                     CRS06360
      XN(I) = XN(I)-DNK(IJ)                                     CRS06370
      XX(J) = XX(J)-DXJ(IJ)                                     CRS06380
      XY(J) = XY(J)-DYJ(IJ)                                     CRS06390
      XZ(J) = XZ(J)-DZJ(IJ)                                     CRS06400
      XL(J) = XL(J)-DLJ(IJ)                                     CRS06410
      XM(J) = XM(J)-DMJ(IJ)                                     CRS06420
      XN(J) = XN(J)-DNJ(IJ)                                     CRS06430
      KRUPT = KRUPT+1
      IRUPT(KRUPT) = I
      JRUPT(KRUPT) = J
      TRUPT(KRUPT) = TIME
      PRINT 1040, IJ,L,VEE(IJL),VMAX(IJL)
 1040 FORMAT(1HL'RUPTURE '2I5,1P2E15.6)
      GO TO 1000                                                CRS06590
  230 CONTINUE                                                  CRS06600
      IF (IJPR(IJ).NE.0)  DRM(IJ)=-6.55D0*VEE(IJL-5)
      AIAIJT(1) = AI(1)*AIJ(1)+AI(4)*AIJ(2)+AI(7)*AIJ(3)        CRS06640
      AIAIJT(4) = AI(1)*AIJ(4)+AI(4)*AIJ(5)+AI(7)*AIJ(6)        CRS06650
      AIAIJT(7) = AI(1)*AIJ(7)+AI(4)*AIJ(8)+AI(7)*AIJ(9)        CRS06660
      AIAIJT(2) = AI(2)*AIJ(1)+AI(5)*AIJ(2)+AI(8)*AIJ(3)        CRS06670
      AIAIJT(5) = AI(2)*AIJ(4)+AI(5)*AIJ(5)+AI(8)*AIJ(6)        CRS06680
      AIAIJT(8) = AI(2)*AIJ(7)+AI(5)*AIJ(8)+AI(8)*AIJ(9)        CRS06690
      AIAIJT(3) = AI(3)*AIJ(1)+AI(6)*AIJ(2)+AI(9)*AIJ(3)        CRS06700
      AIAIJT(6) = AI(3)*AIJ(4)+AI(6)*AIJ(5)+AI(9)*AIJ(5)        CRS06710
      AIAIJT(9) = AI(3)*AIJ(7)+AI(6)*AIJ(8)+AI(9)*AIJ(9)        CRS06720
C (13A)                                                         CRS06730
      T1 = AIAIJT(1)*D(1)+AIAIJT(4)*D(2)+AIAIJT(7)*D(3)         CRS06760
```

Figure 20. (Continued)

```
      T2 = AIAIJT(2)*D(1)+AIAIJT(5)*D(2)+AIAIJT(8)*D(3)                 CRS06750
      T3 = AIAIJT(3)*D(1)+AIAIJT(6)*D(2)+AIAIJT(9)*D(3)                 CRS06760
      D(1) = T1                                                         CRS06770
      D(2) = T2                                                         CRS06780
      D(3) = T3                                                         CRS06790
C (13B)                                                                 CRS06800
      T1 = AIAIJT(1)*D(4)+AIAIJT(4)*D(5)+AIAIJT(7)*D(6)                 CRS06810
      T2 = AIAIJT(2)*D(4)+AIAIJT(5)*D(5)+AIAIJT(8)*D(6)                 CRS06820
      T3 = AIAIJT(3)*D(4)+AIAIJT(6)*D(5)+AIAIJT(9)*D(6)                 CRS06830
      D(4) = T1                                                         CRS06840
      D(5) = T2                                                         CRS06850
      D(6) = T3                                                         CRS06860
C (17A)                                                                 CRS06870
      DXX = -(AJ(1)*D(1)+AJ(2)*D(2)+AJ(3)*D(3))                         CRS06880
      DXY = -(AJ(4)*D(1)+AJ(5)*D(2)+AJ(6)*D(3))                         CRS06890
      DXZ = -(AJ(7)*D(1)+AJ(8)*D(2)+AJ(9)*D(3))                         CRS06900
      XX(J) = XX(J)+DXX                                                 CRS06910
      XY(J) = XY(J)+DXY                                                 CRS06920
      XZ(J) = XZ(J)+DXZ                                                 CRS06930
      XXJ(IJ) = XXJ(IJ)+DXX                                             CRS06940
      XYJ(IJ) = XYJ(IJ)+DXY                                             CRS06950
      XZJ(IJ) = XZJ(IJ)+DXZ                                             CRS06960
C (17B)                                                                 CRS06970
      DXL = -(AJ(1)*D(4)+AJ(2)*D(5)+AJ(3)*D(6))                         CRS06980
      DXM = -(AJ(4)*D(4)+AJ(5)*D(5)+AJ(6)*D(6))                         CRS06990
      DXN = -(AJ(7)*D(4)+AJ(8)*D(5)+AJ(9)*D(6))                         CRS07000
      XL(J) = XL(J)+DXL                                                 CRS07010
      XM(J) = XM(J)+DXM                                                 CRS07020
      XN(J) = XN(J)+DXN                                                 CRS07030
      XLJ(IJ) = XLJ(IJ)+DXL                                             CRS07040
      XMJ(IJ) = XMJ(IJ)+DXM                                             CRS07050
      XNJ(IJ) = XNJ(IJ)+DXN                                             CRS07060
      IF (IJPR(IJ).EQ.1)  GO TO 700
C (14B)                                                                 CRS07140
      D(4) = D(4)-ZIJ*D(2)+YIJ*D(3)                                     CRS07150
      D(5) = D(5)+ZIJ*D(1)-XIJ*D(3)                                     CRS07160
      D(6) = D(6)-YIJ*D(1)+XIJ*D(2)                                     CRS07170
C (16A)                                                                 CRS07180
      DXX = AI(1)*D(1)+AI(2)*D(2)+AI(3)*D(3)                            CRS07190
      DXY = AI(4)*D(1)+AI(5)*D(2)+AI(6)*D(3)                            CRS07200
      DXZ = AI(7)*D(1)+AI(8)*D(2)+AI(9)*D(3)                            CRS07210
      XX(I) = XX(I)+DXX                                                 CRS07220
      XY(I) = XY(I)+DXY                                                 CRS07230
      XZ(I) = XZ(I)+DXZ                                                 CRS07240
      XXK(IJ) = XXK(IJ)+DXX                                             CRS07250
      XYK(IJ) = XYK(IJ)+DXY                                             CRS07260
      XZK(IJ) = XZK(IJ)+DXZ                                             CRS07270
C (16B)                                                                 CRS07280
      DXL = AI(1)*D(4)+AI(2)*D(5)+AI(3)*D(6)                            CRS07290
      DXM = AI(4)*D(4)+AI(5)*D(5)+AI(6)*D(6)                            CRS07300
      DXN = AI(7)*D(4)+AI(8)*D(5)+AI(9)*D(6)                            CRS07310
      XL(I) = XL(I)+DXL                                                 CRS07320
      XM(I) = XM(I)+DXM                                                 CRS07330
      XN(I) = XN(I)+DXN                                                 CRS07340
      XLK(IJ) = XLK(IJ)+DXL                                             CRS07350
      XMK(IJ) = XMK(IJ)+DXM                                             CRS07360
      XNK(IJ) = XNK(IJ)+DXN                                             CRS07370
C (6A)                                                                  CRS07440
  700 CONTINUE
      T1 = AIAIJT(1)*DD(1)+AIAIJT(4)*DD(2)+AIAIJT(7)*DD(3)              CRS07450
```

Figure 20. (Continued)

```
      T2 = AIAIJT(2)*DD(1)+AIAIJT(5)*DD(2)+AIAIJT(8)*DD(3)                     CRS07460
      T3 = AIAIJT(3)*DD(1)+AIAIJT(6)*DD(2)+AIAIJT(9)*DD(3)                     CRS07470
      DD(1) = T1                                                               CRS07480
      DD(2) = T2                                                               CRS07490
      DD(3) = T3                                                               CRS07500
C (6B)                                                                         CRS07510
      T1 = AIAIJT(1)*DD(4)+AIAIJT(4)*DD(5)+AIAIJT(7)*DD(6)                     CRS07520
      T2 = AIAIJT(2)*DD(4)+AIAIJT(5)*DD(5)+AIAIJT(8)*DD(6)                     CRS07530
      T3 = AIAIJT(3)*DD(4)+AIAIJT(6)*DD(5)+AIAIJY(9)*DD(6)                     CRS07540
      DD(4) = T1                                                               CRS07550
      DD(5) = T2                                                               CRS07560
      DD(6) = T3                                                               CRS07570
C (9A)                                                                         CRS07580
      DXX = -(AJ(1)*DD(1)+AJ(2)*DD(2)+AJ(3)*DD(3))                             CRS07590
      DXY = -(AJ(4)*DD(1)+AJ(5)*DD(2)+AJ(6)*DD(3))                             CRS07600
      DXZ = -(AJ(7)*DD(1)+AJ(8)*DD(2)+AJ(9)*DD(3))                             CRS07610
      DPX(J) = DPX(J)+DXX                                                      CRS07620
      DPY(J) = DPY(J)+DXY                                                      CRS07630
      DPZ(J) = DPZ(J)+DXZ                                                      CRS07640
C (9B)                                                                         CRS07680
      DXL = -(AJ(1)*DD(4)+AJ(2)*DD(5)+AJ(3)*DD(6))                             CRS07690
      DXM = -(AJ(4)*DD(4)+AJ(5)*DD(5)+AJ(6)*DD(6))                             CRS07700
      DXN = -(AJ(7)*DD(4)+AJ(8)*DD(5)+AJ(9)*DD(6))                             CRS07710
      DPL(J) = DPL(J)+DXL                                                      CRS07720
      DPM(J) = DPM(J)+DXM                                                      CRS07730
      DPN(J) = DPN(J)+DXN                                                      CRS07740
      IF ((IJPR(IJ).EQ.1) .GO TO 1000
C (7)                                                                           CRS07780
      DD(4) = DD(4)-ZIJ*DD(2)+YIJ*DD(3)                                        CRS07790
      DD(5) = DD(5)+ZIJ*DD(1)-XIJ*DD(3)                                        CRS07800
      DD(6) = DD(6)-YIJ*DD(1)+XIJ*DD(2)                                        CRS07810
C (8A)                                                                         CRS07820
      DXX = AI(1)*DD(1)+AI(2)*DD(2)+AI(3)*DD(3)                                CRS07830
      DXY = AI(4)*DD(1)+AI(5)*DD(2)+AI(6)*DD(3)                                CRS07840
      DXZ = AI(7)*DD(1)+AI(8)*DD(2)+AI(9)*DD(3)                                CRS07850
      DPX(I) = DPX(I)+DXX                                                      CRS07860
      DPY(I) = DPY(I)+DXY                                                      CRS07870
      DPZ(I) = DPZ(I)+DXZ                                                      CRS07880
C (8B)                                                                         CRS07920
      DXL = AI(1)*DD(4)+AI(2)*DD(5)+AI(3)*DD(6)                                CRS07930
      DXM = AI(4)*DD(4)+AI(5)*DD(5)+AI(6)*DD(6)                                CRS07940
      DXN = AI(7)*DD(4)+AI(8)*DD(5)+AI(9)*DD(6)                                CRS07950
      DPL(I) = DPL(I)+DXL                                                      CRS07960
      DPM(I) = DPM(I)+DXM                                                      CRS07970
      DPN(I) = DPN(I)+DXN                                                      CRS07980
 1000 CONTINUE                                                                 CRS08020
      IS=9*(INDP-1)
      DO 1010 KS=1,9
      IS=IS+1
 1010 AP(KS)=BIJ(IS)
C FINISH COMPUTING DERIVATIVES                                                  CRS08030
      DO 2000 I = 1,NM                                                         CRS08040
      IS = 9*(I-1)                                                             CRS08050
      DO 330 KS = 1,9                                                          CRS08060
      IS = IS+1                                                                CRS08070
      AIDOT(KS) = CIJ(IS)                                                      CRS08080
  330 AI(KS) = BIJ(IS)                                                         CRS08090
C DO CRASH FORCES                                                               CRS08100
      CALL CFORCE                                                              CRS08110
C (20),(23),(24)                                                                CRS08120
```

Figure 20. (Continued)

```
      XA = WGT(I)-ALIFT(I)                                              CRS08130
      SX = XX(I)+XA*AI(3)+XC(1)+DPX(I)                                  CRS08140
      SY = XY(I)+XA*AI(6)+XC(2)+DPY(I)                                  CRS08150
      SZ = XZ(I)+XA*AI(9)+XC(3)+DPZ(I)                                  CRS08160
      SL = XL(I)+XC(4)+DPL(I)                                           CRS08170
      SM = XM(I)+XC(5)+DPM(I)                                           CRS08180
      SN = XN(I)+XC(6)+DPN(I)                                           CRS08190
C GET P,Q,R,U,V,W                                                       CRS08200
      PP = P(I)                                                         CRS08210
      QQ = Q(I)                                                         CRS08220
      RR = R(I)                                                         CRS08230
      UU = U(I)                                                         CRS08240
      VV = V(I)                                                         CRS08250
      WW = W(I)                                                         CRS08260
C MASS                                                                  CRS08270
      WGTI = 1.0/WGT(I)
      ZM = 386.0*WGTI
      XACC(I) = SX*WGTI
      YACC(I) = SY*WGTI
      ZACC(I) = SZ*WGTI
C (25)                                                                  CRS08290
      UDOTI = UDOT(I)                                                   CRS08300
      UDOT(I) = SX*ZM-QQ*WW+RR*VV                                       CRS08310
      VDOTI = VDOT(I)                                                   CRS08320
      VDOT(I) = SY*ZM-RR*UU+PP*WW                                       CRS08330
      WDOTI = WDOT(I)                                                   CRS08340
      WDOT(I) = SZ*ZM-PP*VV+QQ*UU                                       CRS08350
C (26)                                                                  CRS08360
      T1 = -XZI(I)*PP-YZI(I)*QQ+ZI(I)*RR+HEZ(I)                         CRS08370
      T2 = XI(I)*PP-XYI(I)*QQ-XZI(I)*RR+HEX(I)                          CRS08380
      T3 = -XYI(I)*PP+YI(I)*QQ-YZI(I)*RR+HEY(I)                         CRS08390
      SL = SL-QQ*T1+RR*T3                                               CRS08400
      SM = SM-RR*T2+PP*T1                                               CRS08410
      SN = SN-PP*T3+QQ*T2                                               CRS08420
C (25)                                                                  CRS08430
      DEL = DELI(I)                                                     CRS08440
      PDOTI = PDOT(I)                                                   CRS08450
      PDOT(I) = DEL*(SL*XI1(I)+SM*XI2(I)+SN*XI3(I))                     CRS08460
      QDOTI = QDOT(I)                                                   CRS08470
      QDOT(I) = DEL*(SL*XI2(I)+SM*XI5(I)+SN*XI4(I))                     CRS08480
      RDOTI = RDOT(I)                                                   CRS08490
      RDOT(I) = DEL*(SL*XI3(I)+SM*XI4(I)+SN*XI5(I))                     CRS08500
      IF(TIME) 2000,2000,300                                            CRS08600
  300 U(I) = TT*U(I)+ET*(UOLD(I)+DTHALF*(UDOT(I)+UDOTI))                CRS08530
      V(I) = TT*V(I)+ET*(VOLD(I)+DTHALF*(VDOT(I)+VDOTI))                CRS08540
      W(I) = TT*W(I)+ET*(WOLD(I)+DTHALF*(WDOT(I)+WDOTI))                CRS08550
      P(I) = TT*P(I)+ET*(POLD(I)+DTHALF*(PDOT(I)+PDOTI))                CRS08560
      Q(I) = TT*Q(I)+ET*(QOLD(I)+DTHALF*(QDOT(I)+QDOTI))                CRS08570
      R(I) = TT*R(I)+ET*(ROLD(I)+DTHALF*(RDOT(I)+RDOTI))                CRS08580
      PIN(I) = TT*PIN(I)+ET*(PINO(I)+DTHALF*(P(I)+POLD(I)))             CRS08670
      QIN(I) = TT*QIN(I)+ET*(QINO(I)+DTHALF*(Q(I)+QOLD(I)))             CRS08680
      RIN(I) = TT*RIN(I)+ET*(RINO(I)+DTHALF*(R(I)+ROLD(I)))             CRS08690
      IF ((IPENSW(I).NE.0).OR.(I.EQ.INDP).OR.(INDP.EQ.3))  GO TO 2000
C
C        CONTROL VOLUME PENETRATION CALCULATIONS
C
      TP1=X(I)-X(INDP)
      TP2=Y(I)-Y(INDP)
      TP3=Z(I)-Z(INDP)
      XPI=AP(1)*TP1+AP(2)*TP2+AP(3)*TP3
```

Figure 20. (Continued)

```
      YPI=AP(4)*TP1+AP(5)*TP2+AP(6)*TP3
      ZPI=AP(7)*TP1+AP(8)*TP2+AP(9)*TP3
      IF ((-XNBAR.GT.XPI).OR.(XPI.GT.XPBAR))  GO TO 2000
      IF ((-YNBAR.GT.YPI).OR.(YPI.GT.YPBAR))  GO TO 2000
      IF ((-ZNBAR.GT.ZPI).OR.(ZPI.GT.ZPBAR))  GO TO 2000
      KPEN=KPEN+1
      IPEN(KPEN)=I
      TPEN(KPEN)=TIME
      IPENSW(I)=1
      PRINT 1080, I,TIME
 1080 FORMAT(1H0,' CONTROL VOLUME PENETRATED BY MASS ',I2,', TIME=',
     1 F10.5)
 2000 CONTINUE                                                          CRS08700
      RETURN                                                            CRS08710
      END                                                               CRS08720
      SUBROUTINE DOAIJ                                                  CRS08730
      IMPLICIT REAL*8 (A-H,O-Z)
      REAL*4 PLOT(30000),ZAR,TMPLOT(500)
      DIMENSION SC(40,3),ZAR(200),IPLOT(150),IDPLOT(150)
      DIMENSION IG(80),JG(80),PHIIJ(80),THEIJ(80),PSIIJ(80),WGT(40),   CRS06640
     1  XI(40),YI(40),ZI(40),XYI(40),YZI(40),XZI(40),HEX(40),HEY(40),  CRS06650
     2  HEZ(40),ALIFT(40),X(40),Y(40),Z(40),PHI(40),THETA(40),PSI(40), CRS06660
     3  U(40),V(40),W(40),P(40),Q(40),R(40),XDOT(40),YDOT(40),ZDOT(40),CRS06670
     4  PHIDOT(40),THEDOT(40),PSIDOT(40),UDOT(40),VDOT(40),WDOT(40)     CRS06680
      DIMENSION AIJ(9),AI(9),AJ(9),AIDOT(9),DX(40),DY(40),DZ(40),       CRS06690
     1  DPHI(40),DTHETA(40),DPSI(40),D(6),DF(6),XX(40),XY(40),XZ(40),   CRS06700
     2  XL(40),XM(40),XN(40),DELI(40),XI1(40),XI2(40),XI3(40),         CRS06710
     3  XI4(40),XI5(40),XI6(40),XK(2880),FMBAR(2880),FMBAR3(6,6,80),   CRS06720
     4  FM(2880),XKRIN(10,6,80),VEE(480),VMAX(480),NN(40,3),NN2(40,3)  CRS06730
      DIMENSION XKI3(9,6,80),BIJ(360),CIJ(360),DIJ(720),XLBAR(40,3),    CRS06740
     1  XXLBAR(3),ISP(40,3),IISP(3),XMU(40,3),XKE(40,3),CAI(360),       CRS06750
     2  IBS(40,3),IBS2(40,3),SI(40,3),SF(40,3),FSPOF(40,3),PHIDP(40),   CRS06760
     3  THEDP(40),PSIDP(40),FSPBAR(40,3),FSPBA2(40,3),XLNGTH(3),XC(6),  CRS06770
     4  XDP(40),YDP(40),ZDP(40),FM3(6,6,80),VEE2(6,80),VEEDOT(3,3)      CPS06780
      DIMENSION PDOT(40),QDOT(40),RDOT(40),N(480),N3(80,6),DVSIGN(6),   CRS06790
     1  XKS(4320),XKS3(9,6,80),XKI(4320),TITLE(10)                      CRS00180
      DIMENSION XOLD(40),YOLD(40),ZOLD(40),PHIOLD(40),THEOLD(40),       CRS06810
     1  PSIOLD(40),POLD(40),QOLD(40),ROLD(40),UOLD(40),VOLD(40),WOLD(40)CRS06820
      DIMENSION XXK(80),XXJ(80),XYK(80),XYJ(80),XZK(80),XZJ(80),        CRS06830
     1  XLK(80),XLJ(80),XMK(80),XMJ(80),XNK(80),XNJ(80)                 CRS06840
      DIMENSION OXIJ(80),OYIJ(80),OZIJ(80)                              CRS06850
      DIMENSION PIN(40),QIN(40),RIN(40),PINO(40),QINO(40),RINO(40),     CRS00230
     1  DPIN(40),DQIN(40),DRIN(40)                                      CRS00240
      DIMENSION SINCOS(6)                                               CRS08980
      DIMENSION DD(6),DPX(40),DPY(40),DPZ(40),DPL(40),DPM(40),DPN(40)   CRS00250
      DIMENSION XIIJ(3),PROD(9),XTHOLD(9,2),XYZIJI(9),XYZIJJ(9)
      DIMENSION C(6,80),CBAR(80),DXDA(6,80)
      DIMENSION XK3(6,6,80)                                             CRS09040
      DIMENSION XACC(40),YACC(40),ZACC(40)
      DIMENSION SUMDF(6,80),TRUPT(80),IRUPT(80),JRUPT(80)
      DIMENSION TPEN(80),IPEN(80)
      DIMENSION IJPR(76)
      DIMENSION AITAJ(9)
      DIMENSION FSPOI(40,3),SA(40,3),SB(40,3)
      DIMENSION ORI(76)
      COMMON ORI
      COMMON FSPOI,SA,SB
      COMMON AITAJ
      COMMON XNBAR,XPBAR,YNBAR,YPBAR,ZNBAR,ZPBAR,TPEN
      COMMON SUMDF,TRUPT,DXDA,SC
      COMMON XACC,YACC,ZACC
      COMMON C,CBAR                                                     CRS09050
      COMMON DD,DPX,DPY,DPZ,DPL,DPM,DPN                                 CRS00300
      COMMON PIN,QIN,RIN,PINO,QINO,RINO,DPIN,DQIN,DRIN                  CPS09080
      COMMON OXIJ,OYIJ,OZIJ,ZG                                          CRS09090
      COMMON XXK,XXJ,XYK,XYJ,XZK,XZJ,XLK,XLJ,XMK,XMJ,XNK,XNJ            CRS09100
      COMMON XOLD,YOLD,ZOLD,PHIOLD,THEOLD,PSIOLD,POLD,QOLD,ROLD,UOLD,   CRS09110
     1  VOLD,WOLD,DT2,DTHALF                                            CRS09120
      COMMON PHI,THETA,PSI                                              CRS09130
      COMMON BIJ,PSIDOT,THEDOT,PHIDOT,CIJ,X,Y,Z,XIJ,YIJ,ZIJ,D,DF        CRS09140
      COMMON AI,AIDOT,AJ,AIJ,DX,DY,DZ,DPHI,DTHETA,DPSI,DVSIGN           CRS09150
      COMMON                        VEE,FMBAR,FM,XKS,XKI,VMAX           CRS00400
      COMMON XX,XY,XZ,XL,XM,XN,WGT,ALIFT,XC,P,Q,R,U,V,W                 CRS09170
      COMMON UDOT,VDOT,WDOT,XZI,YZI,ZI,HEZ,XI,XYI,HEX,YI,HEY,DELI       CRS09180
      COMMON PDOT,XI1,XI2,XI3,QDOT,XI5,XI4,RDOT,XI6,XDOT,YDOT,ZDOT      CRS09190
```

Figure 20. (Continued)

```
      COMMON         XLBAR,SF,FSPOF,XKE,FSPBAR,XMU,VEEDOT                CRS00440
      COMMON XGDOT,YGDOT,ZGDOT,PPR,QPR,RPR,PHIPR,THEPR,PSIPR             CRS00360
      COMMON PHIDP,THEDP,PSIDP,XDP,YDP,ZDP,OAI,DELTAT,TMAX,TIME,TITLE    CRS09220
      COMMON PHIIJ,THEIJ,PSIIJ,XK,DIJ,XXLBAR,SI,XLNGTH,IP                CRS00470
      COMMON NM,I,J,ILAST,ITABIJ,ITAB6,IJLIJ,IJKLIJ,IJKK,IJL,IG,JG,ITAB,CRS09240
     1  ITABO,IJKL,ITABL1,IPRINT,ITABLE,ILINES,NPR,IGS,IISP,ISP,IBS,N,NNCRS00490
      COMMON KRUPT,IRUPT,JRUPT
      COMMON INDP,IPEN,KPEN
      COMMON IJPR
      COMMON PLOT,ZAR,TMPLOT,IPLOT,IDPLOT,IPLSW,IPLC,JPLOT,NPLOT,ITPLOT
      EQUIVALENCE (XKS(1),XKS3(1,1,1)),(XKI(1),XKI3(1,1,1)),             CRS07030
     1  (XKRIN(1,1,1),FMBAR(1)),(FM(1),FM3(1,1,1)),(VEE(1),VEE2(1,1))    CRS07040
      EQUIVALENCE (XTHOLD(1,1),XYZIJI(1)), (XTHOLD(1,2),XYZIJJ(1))
      EQUIVALENCE (FMBAR(1),FMBAR3(1,1,1)),(N(1),N3(1 1)),(NN(1,1),      CRS07050
     1  NN2(1,1)),(FSPBAR(1,1),FSPBA2(1,1)),(IBS(1,1),IBS2(1,1))         CRS07060
      EQUIVALENCE (S1,SINCOS(1)),(C1,SINCOS(2)),(S2,SINCOS(3))           CRS09300
      EQUIVALENCE (C2,SINCOS(4)),(S3,SINCOS(5)),(C3,SINCOS(6))           CRS09310
      EQUIVALENCE (XK(1),XK3(1,1,1))                                      CRS0926
      SIN(X) = DSIN(X)                                                   CRS07070
      COS(X) = DCOS(X)                                                   CRS07080
      SQRT(X) = DSQRT(X)
      IOLD=0
      DO 100 I=1,NM
      ARG=PHI(I)
      S1=SIN(ARG)
      C1=COS(ARG)
      ARG=THETA(I)
      S2=SIN(ARG)
      C2=COS(ARG)
      ARG=PSI(I)
      S3=SIN(ARG)
      C3=COS(ARG)
      DO 85 J=1,6
      T=SINCOS(J)
      IF (T) 70,85,75
   70 T=-T
   75 IF (T-1.E-10) 80,85,85
   80 SINCOS(J)=0.
   85 CONTINUE
      J=9*(I-1)
C MOVE AI'S TO OLD AI'S
      DO 90 JJ=1,9
   90 OAI(J+JJ)=BIJ(J+JJ)
      S1S2=S1*S2
      C1S2=C1*S2
      BIJ(J+1)=C2*C3
      BIJ(J+2)=C2*S3
      BIJ(J+3)=-S2
      BIJ(J+4)=-C1*S3+S1S2*C3
      BIJ(J+5)=C1*C3+S1S2*S3
      BIJ(J+6)=S1*C2
      BIJ(J+7)=S1*S3+C1S2*C3
      BIJ(J+8)=-S1*C3+C1S2*S3
      BIJ(J+9)=C1*C2
  100 CONTINUE
C
      DO 10 IJ = 1,IGS                                                   CRS09320
      S1 = SIN(PHIIJ(IJ))                                                CRS09330
      C1 = COS(PHIIJ(IJ))                                                CRS09340
      S2 = SIN(THEIJ(IJ))                                                CRS09350
```

Figure 20. (Continued)

```
      C2 = COS(THEIJ(IJ))                                              CRS09360
      S3 = SIN(PSIIJ(IJ))                                              CRS09370
      C3 = COS(PSIIJ(IJ))                                              CRS09380
      DO 40 J = 1,6                                                    CRS09390
      T = SINCOS(J)                                                    CRS09400
      IF(T) 45,40,50                                                   CRS09410
   45 T = -T                                                           CRS09420
   50 IF(T-1.E-10) 55,40,40                                            CRS09430
   55 SINCOS(J) = 0.0                                                  CRS09440
   40 CONTINUE                                                         CRS09450
      AIJ(1) = C2*C3                                                   CRS09460
      AIJ(2) = C2*S3                                                   CRS09470
      AIJ(3) = -S2                                                     CRS09480
      AIJ(4) = -C1*S3+S1*S2*C3                                         CRS09490
      AIJ(5) = C1*C3+S1*S2*S3                                          CRS09500
      AIJ(6) = S1*C2                                                   CRS09510
      AIJ(7) = S1*S3+C1*S2*C3                                          CRS09520
      AIJ(8) = -S1*C3+C1*S2*S3                                         CRS09530
      AIJ(9) = C1*C2                                                   CRS09540
      I = 9*(IJ-1)                                                     CRS09550
      DO 15 J = 1,9                                                    CRS09560
   15 BIJ(I+J) = AIJ(J)                                                CRS09570
      CBIJ = CBAR(IJ)                                                  CRS09580
      I = IG(IJ)                                                       CRS09590
      J = JG(IJ)                                                       CRS09600
      IF ((IOLD.NE.0).AND.(I.EQ.IOLD))  GO TO 120
      IS=9*(I-1)
      DO 110 JJ=1,9
      IS=IS+1
  110 AI(JJ)=BIJ(IS)
  120 IOLD=I
      IS=9*(J-1)
      DO 125 JJ=1,9
      IS=IS+1
  125 AJ(JJ)=BIJ(IS)
      AITAJ(1)=AI(1)*AJ(1)+AI(2)*AJ(2)+AI(3)*AJ(3)
      AITAJ(2)=AI(4)*AJ(1)+AI(5)*AJ(2)+AI(6)*AJ(3)
      AITAJ(3)=AI(7)*AJ(1)+AI(8)*AJ(2)+AI(9)*AJ(3)
      AITAJ(4)=AI(1)*AJ(4)+AI(2)*AJ(5)+AI(3)*AJ(6)
      AITAJ(5)=AI(4)*AJ(4)+AI(5)*AJ(5)+AI(6)*AJ(6)
      AITAJ(6)=AI(7)*AJ(4)+AI(8)*AJ(5)+AI(9)*AJ(6)
      AITAJ(7)=AI(1)*AJ(7)+AI(2)*AJ(8)+AI(3)*AJ(9)
      AITAJ(8)=AI(4)*AJ(7)+AI(5)*AJ(8)+AI(6)*AJ(9)
      AITAJ(9)=AI(7)*AJ(7)+AI(8)*AJ(8)+AI(9)*AJ(9)
C
C COMPUTE DAMPING COEFFICIENT MATRIX C
      KKS=I
      DO 312 KS-1,2
      IF (KS.EQ.2)  KKS=J
      XTHOLD(1,KS)=XI(KKS)
      XTHOLD(2,KS)=XYI(KKS)
      XTHOLD(3,KS)=XZI(KKS)
      XTHOLD(4,KS)=XYI(KKS)
      XTHOLD(5,KS)=YI(KKS)
      XTHOLD(6,KS)=YZI(KKS)
      XTHOLD(7,KS)=XZI(KKS)
      XTHOLD(8,KS)=YZI(KKS)
  312 XTHOLD(9,KS)=ZI(KKS)
C
      PROD(1)=AITAJ(1)*XYZIJJ(1)+AITAJ(4)*XYZIJJ(2)+AITAJ(7)*XYZIJJ(3)
```

Figure 20. (Continued)

```
      PROD(2)=AITAJ(2)*XYZIJJ(1)+AITAJ(5)*XYZIJJ(2)+AITAJ(8)*XYZIJJ(3)
      PROD(3)=AITAJ(3)*XYZIJJ(1)+AITAJ(6)*XYZIJJ(2)+AITAJ(9)*XYZIJJ(3)
      PROD(4)=AITAJ(1)*XYZIJJ(4)+AITAJ(4)*XYZIJJ(5)+AITAJ(7)*XYZIJJ(6)
      PROD(5)=AITAJ(2)*XYZIJJ(4)+AITAJ(5)*XYZIJJ(5)+AITAJ(8)*XYZIJJ(6)
      PROD(6)=AITAJ(3)*XYZIJJ(4)+AITAJ(6)*XYZIJJ(5)+AITAJ(9)*XYZIJJ(6)
      PROD(7)=AITAJ(1)*XYZIJJ(7)+AITAJ(4)*XYZIJJ(8)+AITAJ(7)*XYZIJJ(9)
      PROD(8)=AITAJ(2)*XYZIJJ(7)+AITAJ(5)*XYZIJJ(8)+AITAJ(8)*XYZIJJ(9)
      PROD(9)=AITAJ(3)*XYZIJJ(7)+AITAJ(6)*XYZIJJ(8)+AITAJ(9)*XYZIJJ(9)
C
      XYZIJJ(1)=PROD(1)*AITAJ(1)+PROD(4)*AITAJ(4)+PROD(7)*AITAJ(7)
      XYZIJJ(2)=PROD(2)*AITAJ(1)+PROD(5)*AITAJ(4)+PROD(8)*AITAJ(7)
      XYZIJJ(3)=PROD(3)*AITAJ(1)+PROD(6)*AITAJ(4)+PROD(9)*AITAJ(7)
      XYZIJJ(4)=PROD(1)*AITAJ(2)+PROD(4)*AITAJ(5)+PROD(7)*AITAJ(8)
      XYZIJJ(5)=PROD(2)*AITAJ(2)+PROD(5)*AITAJ(5)+PROD(8)*AITAJ(8)
      XYZIJJ(6)=PROD(3)*AITAJ(2)+PROD(6)*AITAJ(5)+PROD(9)*AITAJ(8)
      XYZIJJ(7)=PROD(1)*AITAJ(3)+PROD(4)*AITAJ(6)+PROD(7)*AITAJ(9)
      XYZIJJ(8)=PROD(2)*AITAJ(3)+PROD(5)*AITAJ(6)+PROD(8)*AITAJ(9)
      XYZIJJ(9)=PROD(3)*AITAJ(3)+PROD(6)*AITAJ(6)+PROD(9)*AITAJ(9)
      DO 314 KS=1,9
  314 XYZIJI(KS)=XYZIJI(KS)+XYZIJJ(KS)
      PROD(1)=XYZIJI(1)*AIJ(1)+XYZIJI(4)*AIJ(2)+XYZIJI(7)*AIJ(3)
      PROD(2)=XYZIJI(2)*AIJ(1)+XYZIJI(5)*AIJ(2)+XYZIJI(8)*AIJ(3)
      PROD(3)=XYZIJI(3)*AIJ(1)+XYZIJI(6)*AIJ(2)+XYZIJI(9)*AIJ(3)
      PROD(4)=XYZIJI(1)*AIJ(4)+XYZIJI(4)*AIJ(5)+XYZIJI(7)*AIJ(6)
      PROD(5)=XYZIJI(2)*AIJ(4)+XYZIJI(5)*AIJ(5)+XYZIJI(8)*AIJ(6)
      PROD(6)=XYZIJI(3)*AIJ(4)+XYZIJI(6)*AIJ(5)+XYZIJI(9)*AIJ(6)
      PROD(7)=XYZIJI(1)*AIJ(7)+XYZIJI(4)*AIJ(8)+XYZIJI(7)*AIJ(9)
      PROD(8)=XYZIJI(2)*AIJ(7)+XYZIJI(5)*AIJ(8)+XYZIJI(8)*AIJ(9)
      PROD(9)=XYZIJI(3)*AIJ(7)+XYZIJI(6)*AIJ(8)+XYZIJI(9)*AIJ(9)
C
      XIIJ(1)=AIJ(1)*PROD(1)+AIJ(2)*PROD(2)+AIJ(3)*PROD(3)
      XIIJ(2)=AIJ(4)*PROD(4)+AIJ(5)*PROD(5)+AIJ(6)*PROD(6)
      XIIJ(3)=AIJ(7)*PROD(7)+AIJ(8)*PROD(8)+AIJ(9)*PROD(9)
      DO 20 K = 1,3                                                     CRS09740
   20 C(K,IJ) = .1018D0*C8IJ*SQRT(XK3(K,K,IJ)*(WGT(I)+WGT(J)))          CRS09750
      DO 30 K=4,6
   30 C(K,IJ)=2.*C8IJ*SQRT(XK3(K,K,IJ)*XIIJ(K-3))
   10 CONTINUE                                                          CRS09780
      RETURN                                                            CRS09790
      END                                                               CRSC9800
```

Figure 20. (Continued)

```
      SUBROUTINE LINES                                                  CRS09810
      IMPLICIT REAL*8 (A-H,O-Z)
      REAL*4 PLOT(30000),ZAP,TMPLOT(500)
      DIMENSION SC(40,3),ZAR(200),IPLOT(150),IDPLOT(150)
      DIMENSION IG(80),JG(80),PHIIJ(80),THEIJ(80),PSIIJ(80),WGT(40),    CRS07310
     1  XI(40),YI(40),ZI(40),XYI(40),YZI(40),XZI(40),HEX(40),HEY(40),   CRS07320
     2  HEZ(40),ALIFT(40),X(40),Y(40),Z(40),PHI(40),THETA(40),PSI(40),  CRS07330
     3  U(40),V(40),W(40),P(40),Q(40),R(40),XDOT(40),YDOT(40),ZDOT(40), CRS07340
     4  PHIDOT(40),THEDOT(40),PSIDOT(40),UDOT(40),VDOT(40),WDOT(40)     CRS07350
      DIMENSION AIJ(9),AI(9),AJ(9),AIDOT(9),DX(40),DY(40),DZ(40),       CRS07360
     1  DPHI(40),DTHETA(40),DPSI(40),D(6),DF(6),XX(40),XY(40),XZ(40),   CRS07370
     2  XL(40),XM(40),XN(40),DELI(40),XI1(40),XI2(40),XI3(40),          CRS07380
     3  XI4(40),XI5(40),XI6(40),XK(2880),FMBAR(2880),FMBAR3(6,6,80),    CRS07390
     4  F4(2880),XKRIN(10,6,80),VEF(480),VMAX(480),NN(40,3),NN2(40,3)   CRS07400
      DIMENSION XKI3(9,6,80),BIJ(360),CIJ(360),DIJ(720),XLBAR(40,3),    CRS07410
     1  XXLBAR(3),ISP(40,3),IISP(3),XMU(40,3),XKE(40,3),OAI(360),       CRS07420
     2  IBS(40,3),IBS2(40,3),SI(40,3),SF(40,3),FSPOF(40,3),PHIDP(40),   CRS07430
     3  THEDP(40),PSIDP(40),FSPBAR(40,3),FSPBA2(40,3),XLNGTH(3),XC(6),  CRS07440
     4  XDP(40),YDP(40),ZDP(40),FM3(6,6,80),VEE2(6,80),VEEDOT(3,3)      CRS07450
      DIMENSION PDOT(40),QDOT(40),RDOT(40),N(450),N3(33,6),DVSIGN(6),   CRS07460
     1  XKS(4320),XKS3(9,6,80),XKI(4320),TITLE(10)                      CRS00180
      DIMENSION XOLD(40),YOLD(40),ZOLD(40),PHIOLD(40),THEOLD(40),       CRS07480
     1  PSIOLD(40),POLD(40),QOLD(40),ROLD(40),UOLD(40),VOLD(40),WOLD(40)CRS07490
      DIMENSION XXK(80),XXJ(80),XYK(80),XYJ(80),XZK(80),XZJ(80),        CRS07500
     1  XLK(80),XLJ(80),XMK(80),XMJ(80),XNK(80),XNJ(80)                 CRS07510
      DIMENSION DXIJ(80),DYIJ(80),DZIJ(80)                              CRS07520
      DIMENSION PIN(40),QIN(40),RIN(40),PINO(40),QINO(40),RINO(40),     CRS00230
     1  DPIN(40),DQIN(40),DRIN(40)                                      CRS00240
      DIMENSION DD(6),DPX(40),DPY(40),DPZ(40),DPL(40),DPM(40),DPN(40)   CRS00250
      DIMENSION C(6,80),CBAR(80),DXDA(6,80)                             CRS00280
      DIMENSION XACC(40),YACC(40),ZACC(40)
      DIMENSION SUMDF(6,80),TRUPT(80),IRUPT(80),JRUPT(80)
      DIMENSION TPEN(80),IPEN(80)
      DIMENSION IJPR(76)
      DIMENSION AITAJ(9)
      DIMENSION FSPOI(40,3),SA(40,3),SB(40,3)
      DIMENSION DRI(76)
      COMMON DRI
      COMMON FSPOI,SA,SB
      COMMON AITAJ
      COMMON XNBAR,XPBAR,YNBAR,YPBAR,ZNBAR,ZPBAR,TPEN
      COMMON SUMDF,TRUPT,DXDA,SC
      COMMON XACC,YACC,ZACC
      COMMON C,CBAR                                                     CRS10100
      COMMON DD,DPX,DPY,DPZ,DPL,DPM,DPN                                 CRS00300
      COMMON PIN,QIN,RIN,PINO,QINO,RINO,DPIN,DQIN,DRIN                  CRS10130
      COMMON DXIJ,DYIJ,DZIJ,ZG                                          CRS10140
      COMMON XXK,XXJ,XYK,XYJ,XZK,XZJ,XLK,XLJ,XMK,XMJ,XNK,XNJ            CRS10150
      COMMON XOLD,YOLD,ZOLD,PHIOLD,THEOLD,PSIOLD,POLD,QOLD,ROLD,UOLD,   CRS10160
     1  VOLD,WOLD,DT2,DTHALF                                            CRS10170
      COMMON PHI,THETA,PSI                                              CRS10180
      COMMON BIJ,PSIDOT,THEDOT,PHIDOT,CIJ,X,Y,Z,XIJ,YIJ,ZIJ,D,DF        CRS10190
      COMMON AI,AIDOT,AJ,AIJ,DX,DY,DZ,DPHI,DTHETA,DPSI,DVSIGN           CRS10200
      COMMON                    VEE,FMBAR,FM,XKS,XKI,VMAX               CRS00400
      COMMON XX,XY,XZ,XL,XM,XN,WGT,ALIFT,XC,P,Q,R,U,V,W                 CRS10220
      COMMON UDOT,VDOT,WDOT,XZI,YZI,ZI,HEZ,XI,XYI,HEX,YI,HEY,DELI       CRS10230
      COMMON PDOT,XI1,XI2,XI3,QDOT,XI5,XI4,RDOT,XI6,XDOT,YDOT,ZDOT      CRS10240
      COMMON             XLBAR,SF,FSPOF,XKE,FSPBAR,XMU,VEEDOT           CRS00440
      COMMON XGDOT,YGDOT,ZGDOT,PPR,QPR,RPR,PHIPR,THEPR,PSIPR            CRS00360
      COMMON PHIDP,THEDP,PSIDP,XDP,YDP,ZDP,OAI,DELTAT,TMAX,TIME,TITLE   CRS10270
```

Figure 20. (Continued)

```
      COMMON PHIIJ,THEIJ,PSIIJ,XX,DIJ,XXLBAR,SI,XLNGTH,IP               CRS00470
      COMMON NM,I,J,ILAST,ITABIJ,ITAB6,IJLIJ,IJKLIJ,IJKK,IJL,IG,JG,ITAB,CRS10290
     1  ITABD,IJKL,ITABLI,IPRINT,ITABLE,ILINES,NPP,IGS,IISP,ISP,IBS,N,NNCRS00490
      COMMON KRUPT,IRUPT,JRUPT
      COMMON INDP,IPEN,KPEN
      COMMON IJPR
      COMMON PLOT,ZAR,TMPLOT,IPLOT,IDPLOT,IPLSW,IPLC,JPLOT,NPLOT,ITPLOT
      EQUIVALENCE (XKS(1),XKS3(1,1,1)),(XKI(1),XKI3(1,1,1)),            CRS07700
     1  (XKRIN(1,1,1),FM3AR(1)),(FM(1),FM3(1,1,1)),(VEE(1),VEE2(1,1))   CRS07710
      EQUIVALENCE (FMBAR(1),FMBAR3(1,1,1)),(N(1),N3(1,1)),(NN(1,1),     CRS07720
     1  NN2(1,1)),(FSPBAR(1,1),FSPBA2(1,1)),(IBS(1,1),IBS2(1,1))        CRS07730
      DO 10 IJ = 1,IGS                                                  CRS10340
      DO 10 L = 1,6                                                     CRS10350
      XO = -DXDA(L,IJ)                                                  CRS10370
      DELX = DXDA(L,IJ)                                                 CRS10380
   40 DO 10 I = 1,ITABLI                                                CRS10420
      XO = XO+DELX                                                      CRS10430
      T = (XKRIN(I+1,L,IJ)-XKRIN(I,L,IJ))/DELX                          CRS10440
      XKS3(I,L,IJ) = T                                                  CRS10450
   10 XKI3(I,L,IJ) = XKRIN(I,L,IJ)-XO*T                                 CRS10460
      RETURN                                                            CRS10470
      END                                                               CRS10480
      SUBROUTINE CFORCE                                                 CRS10490
      IMPLICIT REAL*8 (A-H,O-Z)
      REAL*4 PLOT(30000),ZAR,TMPLOT(500)
      DIMENSION SC(40,3),ZAR(200),IPLOT(150),IDPLOT(150)
      DIMENSION IG(80),JG(80),PHIIJ(80),THEIJ(80),PSIIJ(80),WGT(40),    CRS07910
     1  XI(40),YI(40),ZI(40),XYI(40),YZI(40),XZI(40),HEX(40),HEY(40),   CRS07920
     2  HEZ(40),ALIFT(40),X(40),Y(40),Z(40),PHI(40),THETA(40),PSI(40),  CRS07930
     3  U(40),V(40),W(40),P(40),Q(40),R(40),XDOT(40),YDOT(40),ZDOT(40), CRS07940
     4  PHIDOT(40),THEDOT(40),PSIDOT(40),UDOT(40),VDOT(40),WDOT(40)     CRS07950
      DIMENSION AIJ(9),AI(9),AJ(9),AIDOT(9),DX(40),DY(40),DZ(40),       CRS07960
     1  DPHI(40),DTHETA(40),DPSI(40),D(6),DF(6),XX(40),XY(40),XZ(40),   CRS07970
     2  XL(40),XM(40),XN(40),DELI(40),XI1(40),XI2(40),XI3(40),          CRS07980
     3  XI4(40),XI5(40),XI6(40),XK(2880),FMBAR(2880),FMBAR3(6,6,80),    CRS07990
     4  FM(2880),XKRIN(10,6,80),VEE(480),VMAX(480),NN(40,3),NN2(40,3)   CRS08000
      DIMENSION XKI3(9,6,80),BIJ(360),CIJ(360),DIJ(720),XLBAR(40,3),    CRS08010
     1  XXLBAR(3),ISP(40,3),IISP(3),XMU(40,3),XKE(40,3),DAI(360),       CRS08020
     2  IBS(40,3),IBS2(40,3),SI(40,3),SF(40,3),FSPOF(40,3),PHIDP(40),   CRS08030
     3  THEDP(40),PSIDP(40),FSPBAR(40,3),FSPBA2(40,3),XLNGTH(3),XC(6),  CRS08040
     4  XDP(40),YDP(40),ZDP(40),FM3(6,6,80),VEE2(6,80),VEEDOT(3,3)      CRS08050
      DIMENSION PDOT(40),QDOT(40),RDOT(40),N(480),N3(80,6),DVSIGN(6),   CRS08060
     1  XKS(4320),XKS3(9,6,80),XKI(4320),TITLE(10)                      CRS00180
      DIMENSION VA(3),VADOT(3),PBAR(3),PL(3,3),FSP(3,3),XVOC(3,3)       CRS08080
      DIMENSION C1(3),C2(3),VC3(3),                 S(3),SDOT(3)        CRS08090
      DIMENSION XOLD(40),YOLD(40),ZOLD(40),PHIOLD(40),THEOLD(40),       CRS08100
     1  PSIOLD(40),POLD(40),QOLD(40),ROLD(40),UOLD(40),VOLD(40),WOLD(40)CRS08110
      DIMENSION XXK(80),XXJ(80),XYK(80),XYJ(80),XZK(80),XZJ(80),        CRS08120
     1  XLK(80),XLJ(80),XMK(80),XMJ(80),XNK(80),XNJ(80)                 CRS08130
      DIMENSION DXIJ(80),DYIJ(80),DZIJ(80)                              CRS08140
      DIMENSION PIN(40),QIN(40),RIN(40),PINO(40),QINO(40),RINO(40),     CRS00230
     1  DPIN(40),DQIN(40),DRIN(40)                                      CRS00240
      DIMENSION DD(6),DPX(40),DPY(40),DPZ(40),DPL(40),DPH(40),DPN(40)   CRS00250
      DIMENSION C(6,80),CBAR(80),DXDA(6,80)                             CRS00260
      DIMENSION XACC(40),YACC(40),ZACC(40)
      DIMENSION SUMDF(6,80),TRUPT(80),IRUPT(80),JRUPT(80)
      DIMENSION TPEN(80),IPEN(80)
      DIMENSION IJPR(76)
      DIMENSION AITAJ(9)
      DIMENSION FSPOI(40,3),SA(40,3),SB(40,3)
```

Figure 20. (Continued)

```
      DIMENSION DRI(76)
      COMMON DRI
      COMMON FSPOI,SA,SB
      COMMON AITAJ
      COMMON XNBAR,XPBAR,YNBAR,YPBAR,ZNBAR,ZPBAR,TPEN
      COMMON SUMDF,TRUPT,DXOA,SC
      COMMON XACC,YACC,ZACC
      COMMON C,CBAR                                                     CRS10800
      COMMON DD,DPX,DPY,DPZ,DPL,DPM,DPN                                 CRS00300
      COMMON PIN,QIN,RIN,PINO,QINO,RINO,DPIN,DQIN,DRIN                  CRS10830
      COMMON DXIJ,DYIJ,DZIJ,ZG                                          CRS10840
      COMMON XXK,XXJ,XYK,XYJ,XZK,XZJ,XLK,XLJ,XMK,XMJ,XNK,XNJ            CRS10850
      COMMON XOLD,YOLD,ZOLD,PHIOLD,THEOLD,PSIOLD,POLD,QOLD,ROLD,UOLD,   CRS10860
     1  VOLD,WOLD,DT2,DTHALF                                            CRS10870
      COMMON PHI,THETA,PSI                                              CRS10880
      COMMON BIJ,PSIDOT,THEDOT,PHIDOT,CIJ,X,Y,Z,XIJ,YIJ,ZIJ,D,DF        CRS10890
      COMMON AI,AIDOT,AJ,AIJ,DX,DY,DZ,DPHI,DTHETA,DPSI,DVSIGN           CRS10900
      COMMON                    VEE,FMBAR,FM,XKS,XKI,VMAX               CRS00400
      COMMON XX,XY,XZ,XL,XM,XN,WGT,ALIFT,XC,P,Q,R,U,V,W                 CRS10920
      COMMON UDOT,VDOT,WDOT,XZI,YZI,ZI,HFZ,XI,XYI,HFX,YI,HEY,DELI       CRS10930
      COMMON PDOT,XI1,XI2,XI3,QDOT,XI5,XI4,RDOT,XI6,XDOT,YDOT,ZDOT      CRS10940
      COMMON              XLBAR,SF,FSPOF,XKE,FSPBAR,XMU,VEEDOT          CRS00440
      COMMON XGDOT,YGDOT,ZGDOT,PPR,QPR,RPR,PHIPR,THEPR,PSIPR            CRS00360
      COMMON PHIOP,THEOP,PSIOP,XOP,YOP,ZOP,OAI,DELTAT,TMAX,TIME,TITLE   CRS10970
      COMMON PHIIJ,THEIJ,PSIIJ,XK,DIJ,XXLBAR,SI,XLNGTH,IP               CRS00470
      COMMON NM,I,J,ILAST,ITABIJ,ITAB6,IJLIJ,IJKLIJ,IJKK,IJL,IG,JG,ITAB,CRS10990
     1  ITABD,IJKL,ITABL1,IPRINT,ITABLE,ILINES,NPR,IGS,IISP,ISP,IBS,N,NNCRS00490
      COMMON KRUPT,IRUPT,JRUPT
      COMMON INDP,ZPEN,XPEN
      COMMON IJPR
      COMMON PLOT,ZAR,TMPLOT,IPLOT,IOPLOT,IPLSW,IPLC,JPLOT,NPLOT,ITPLOT
      EQUIVALENCE (XKS(1),XKS3(1,1,1)),(XKI(1),XKI3(1,1,1)),            CRS08320
     1  (XKRIN(1,1,1),FMBAR(1)),(FM(1),FM3(1,1,1)),(VEE(1),VEE2(1,1))   CRS08330
      EQUIVALENCE (FMBAR(1),FMBAR3(1,1,1)),(N(1),N3(1,1)),(NN(1,1),     CRS08340
     1  NN2(1,1)),(FSPBAR(1,1),FSPBA2(1,1)),(IBS(1,1),IBS2(1,1))        CRS08350
      SQRT(X) = DSQRT(X)                                                CRS08360
      VA(1) = X(I)                                                      CRS11040
      VA(2) = Y(I)                                                      CRS11050
      VA(3) = Z(I)                                                      CRS11060
      VADOT(1) = XDOT(I)                                                CRS11070
      VADOT(2) = YDOT(I)                                                CRS11080
      VADOT(3) = ZDOT(I)                                                CRS11090
      PBAR(1) = P(I)                                                    CRS11100
      PBAR(2) = Q(I)                                                    CRS11110
      PBAR(3) = R(I)                                                    CRS11120
C INITIALIZE SOME MORE                                                  CRS11130
      DO 10 K = 1,3                                                     CRS11140
      XLNGTH(K) = 0.0                                                   CRS11150
      IISP(K) = ISP(I,K)                                                CRS11160
      XXLBAR(K) = XLBAR(I,K)                                            CRS11170
      DO 15 JJ = 1,3                                                    CRS11180
      FSP(JJ,K) = 0.0                                                   CRS11190
   15 XMOC(JJ,K) = 0.0                                                  CRS11200
   10 CONTINUE                                                          CRS11210
C LOOP G                                                                CRS11220
      DO 20 K = 1,3                                                     CRS11230
      IF(IISP(K)) 25,20,25                                              CRS11240
   25 ISUB = 3*K                                                        CRS11250
      DVC = AI(ISUB)*XXLBAR(K)                                          CRS11260
      DVCDOT = AIDOT(ISUB)*XXLBAR(K)                                    CRS11270
```

Figure 20. (Continued)

```
      VC = VA(3)+DVC                                                    CRS11280
      VCDOT = VADOT(3)+DVCDOT                                           CRS11290
      C1(K) = VC/DVC                                                    CRS11300
      C2(K) = (DVC*VCDOT-VC*DVCDOT)/(DVC*DVC)                           CRS11310
      VC3(K) = VC                                                       CRS11320
   20 CONTINUE                                                          CRS11330
C LOOP H                                                                CRS11340
      DO 30 K = 1,3                                                     CRS11350
      IF(IISP(K)) 35,30,35                                              CRS11360
   35 IF(VC3(K)) 30,30,40                                               CRS11370
   40 ISUB = 3*(K-1)                                                    CRS11380
      BARL = XXLBAR(K)                                                  CRS11390
      SUM = 0.0                                                         CRS11400
      SUMD = 0.0                                                        CRS11410
C LOOP J                                                                CRS11420
      DO 50 J = 1,3                                                     CRS11430
      ISUB = ISUB+1                                                     CRS11440
      DVC = AI(ISUB)*BARL                                               CRS11450
      DVCDOT = AIDOT(ISUB)*BARL                                         CRS11460
      DVP = C1(K)*DVC                                                   CRS11470
      DDP = C1(K)*DVCDOT+C2(K)*DVC                                      CRS11480
      SUM = SUM+DVP*DVP                                                 CRS11490
      SUMD = SUMD+DVP*DDP                                               CRS11500
   50 CONTINUE                                                          CRS11510
      SK = SQRT(SUM)                                                    CRS11520
      S(K) = SK                                                         CRS11530
      SC(I,K) = SK
      SDOT(K) = SUMD/SK                                                 CRS11540
C GET LENGTH                                                            CRS11550
      IF(BARL) 55,60,60                                                 CRS11560
   55 T = -BARL-SK                                                      CRS11570
      IF(T) 65,65,70                                                    CRS11580
   70 T = -T                                                            CRS11590
      GO TO 65                                                          CRS11600
   60 T = BARL-SK                                                       CRS11610
      IF(T) 70,65,65                                                    CRS11620
   65 XLNGTH(K) = T                                                     CRS11630
   30 CONTINUE                                                          CRS11640
      PL(1,1) = -SDOT(1)                                                CRS11650
      PL(2,2) = -SDOT(2)                                                CRS11660
      PL(3,3) = -SDOT(3)                                                CRS11670
      PL(2,1) = PBAR(3)*XLNGTH(1)                                       CRS11680
      PL(3,1) = -PBAR(2)*XLNGTH(1)                                      CRS11690
      PL(1,2) = -PBAR(3)*XLNGTH(2)                                      CRS11700
      PL(3,2) = PBAR(1)*XLNGTH(2)                                       CRS11710
      PL(1,3) = PBAR(2)*XLNGTH(3)                                       CRS11720
      PL(2,3) = -PBAR(1)*XLNGTH(3)                                      CRS11730
C LOOP K                                                                CRS11740
      DO 75 JJ = 1,3                                                    CRS11750
      ISUB = JJ-3                                                       CRS11760
      VAD = VADOT(JJ)                                                   CRS11770
C LOOP L                                                                CRS11780
      DO 80 K = 1,3                                                     CRS11790
      IF(IISP(K)) 85,80,85                                              CRS11800
   85 IF(VC3(K)) 80,80,90                                               CRS11810
   90 SUM = 0.0                                                         CRS11820
C LOOP M                                                                CRS11830
      DO 95 L = 1,3                                                     CRS11840
      ISUB = ISUB+3                                                     CRS11850
   95 SUM = SUM+AI(ISUB)*PL(L,K)                                        CRS11860
```

Figure 20. (Continued)

```
      VEEDOT(JJ,K) = VAD+SUM
   80 CONTINUE
   75 CONTINUE
C LOOP N
      DO 105 K = 1,3
      IF(IISP(K)) 110,105,110
  110 IF(VCB(K)) 105,105,115
  115 SK = S(K)
      SDIF = SK-SF(I,K)
      IF(SDIF) 120,120,125
  120 IF(IBS(I,K)) 130,130,135
  125 IBS(I,K) = 1
  135 FSPO = FSPOF(I,K)+XKE(I,K)*SDIF
      IF(FSPO) 140,150,190
  140 FSPO = 0.0
      GO TO 190
  130 SP = SK-FSPBAR(I,K)
C FSPBAR = SBAR-FSPOBAR/KE
      IF(SP) 150,155,155
  150 FSPO = 0.0
      GO TO 160
C  COMPUTE FSPO PER NEW EXTERNAL SPRING LOAD-STROKE CURVES 7/25/72
  155 FSPO=FSPOF(I,K)
      IF (SP.GE.SB(I,K))  GO TO 160
      IF (SP.GT.SA(I,K))  GO TO 157
      FSPO=FSPOI(I,K)
      IF (SP.GE.SI(I,K))  GO TO 160
      FSPO=FSPO*SP/SI(I,K)
      GO TO 160
  157 FSPO=FSPOI(I,K)+(SP-SA(I,K))*(FSPO-FSPOI(I,K))/(SB(I,K)-SA(I,K))
  160 IF(SDOT(K)) 165,165,170
  170 NN(I,K) = 0
      GO TO 190
  165 IF(NN(I,K)) 190,175,190
  175 NN(I,K) = 1
      FSPBAR(I,K) = SK-FSPO/XKE(I,K)
C (15A)
  190 XV = AI(3*K)*FSPO
      XVOC(3,K) = XV
      V1 = VEEDOT(1,K)
      V2 = VEEDOT(2,K)
      VBB = SQRT(V1*V1+V2*V2)
      IF(VBB) 210,210,200
  200 XV = XMU(I,K)*XV/VBB
      XVOC(1,K) = XV*VEEDOT(1,K)
      XVOC(2,K) = XV*VEEDOT(2,K)
  210 IS = 0
C LOOP J
      DO 220 J = 1,3
      SUM = 0.0
C LOOP R
      DO 230 L = 1,3
      IS = IS+1
  230 SUM = SUM-AI(IS)*XVOC(L,K)
  220 FSP(J,K) = SUM
C END OF LOOP N
  105 CONTINUE
C CRASH FORCES
      DO 240 J = 1,3
      SUM = 0.0
      DO 250 K = 1,3
  250 SUM = SUM+FSP(J,K)
  240 XC(J) = SUM
C CRASH MOMENTS
      XC(4) = FSP(3,2)*XLNGTH(2)-FSP(2,3)*XLNGTH(3)
      XC(5) = FSP(1,2)*XLNGTH(3)-FSP(3,1)*XLNGTH(1)
      XC(6) = FSP(2,1)*XLNGTH(1)-FSP(1,2)*XLNGTH(2)
C
      RETURN
      END
```

Figure 20. (Continued)

```
      SUBROUTINE EULER(A,PHI,THETA,PSI)                                 CRS12530
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION A(9)                                                    CRS12540
      SIN(X) = DSIN(X)                                                  CRS10010
      COS(X) = DCOS(X)                                                  CRS10020
      S1 = SIN(PHI)                                                     CRS12550
      C1 = COS(PHI)                                                     CRS12560
      S2 = SIN(THETA)                                                   CRS12570
      C2 = COS(THETA)                                                   CRS12580
      S3 = SIN(PSI)                                                     CRS12590
      C3 = COS(PSI)                                                     CRS12600
      A(1) =  C2*C3                                                     CRS12610
      A(2) =  C2*S3                                                     CRS12620
      A(3) = -S2                                                        CRS12630
      A(4) = -C1*S3+S1*S2*C3                                            CRS12640
      A(5) =  C1*C3+S1*S2*S3                                            CRS12650
      A(6) =  S1*C2                                                     CRS12660
      A(7) =  S1*S3+C1*S2*C3                                            CRS12670
      A(8) = -S1*C3+C1*S2*S3                                            CRS12680
      A(9) =  C1*C2                                                     CRS12690
      RETURN                                                            CRS12700
      END                                                               CRS12710
      SUBROUTINE MATMUL(A,B,C)                                          CRS12720
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION A(3,3),B(3,3),C(3,3)                                    CRS12730
C A*B TO C                                                              CRS12740
      DO 10 I = 1,3                                                     CRS12750
      DO 10 J = 1,3                                                     CRS12760
      SUM = 0.0                                                         CRS12770
      DO 20 K = 1,3                                                     CRS12780
   20 SUM = SUM+A(I,K)*B(K,J)                                           CRS12790
   10 C(I,J) = SUM                                                      CRS12800
      RETURN                                                            CRS12810
      END                                                               CRS12820
      SUBROUTINE MATVEC(A,V,P,ISW)                                      CRS12830
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION A(3,3),V(3),P(3)                                        CRS12840
C A*V TO P IF ISW = 0, ELSE AT*V TO P                                   CRS12850
      DO 10 I = 1,3                                                     CRS12860
      SUM = 0.0                                                         CRS12870
      DO 20 K = 1,3                                                     CRS12880
      IF(ISW) 40,30,40                                                  CRS12890
   30 SUM = SUM+A(I,K)*V(K)                                             CRS12900
      GO TO 20                                                          CRS12910
   40 SUM = SUM+A(K,I)*V(K)                                             CRS12920
   20 CONTINUE                                                          CRS12930
   10 P(I) = SUM                                                        CRS12940
      RETURN                                                            CRS12950
      END                                                               CRS12960
```

Figure 20. (Continued)

```
      SUBROUTINE INPLT                                                  CRS12970
      IMPLICIT REAL*8 (A-H,O-Z)
      REAL*4 PLOT(30000),ZAR,TMPLOT(500)
      DIMENSION INBUF(76)
      DIMENSION SC(40,3),ZAR(200),IPLOT(150),IOPLOT(150)
      DIMENSION IG(80),JG(80),PHIIJ(80),THEIJ(80),PSIIJ(80),WGT(40),    CRS10490
     1  XI(40),YI(40),ZI(40),XYI(40),YZI(40),XZI(40),HEX(40),HEY(40),   CRS10500
     2  HEZ(40),ALIFT(40),X(40),Y(40),Z(40),PHI(40),THETA(40),PSI(40),  CRS10510
     3  U(40),V(40),W(40),P(40),Q(40),R(40),XDOT(40),YDOT(40),ZDOT(40), CRS10520
     4  PHIDOT(40),THEDOT(40),PSIDOT(40),UDOT(40),VDOT(40),WDOT(40)     CRS10530
      DIMENSION AIJ(9),AI(9),AJ(9),AIDOT(9),DX(40),DY(40),DZ(40),       CRS10540
     1  DPHI(40),DTHETA(40),DPSI(40),D(6),DF(6),XX(40),XY(40),XZ(40),   CRS10550
     2  XL(40),XM(40),XN(40),DELI(40),XI1(40),XI2(40),XI3(40),          CRS10560
     3  XI4(40),XI5(40),XI6(40),XK(2880),FMBAR(2880),FMBAR3(6,6,80),    CRS10570
     4  FM(2880),XKRIN(10,6,80),VEE(480),VMAX(480),NN(40,3),NN2(40,3)   CRS10580
      DIMENSION XKI3(9,6,80),BIJ(360),CIJ(360),DIJ(720),XLBAR(40,3),    CRS10590
     1  XXLBAR(3),ISP(40,3),IISP(3),XMU(40,3),XKE(40,3),DAI(360),       CRS10600
     2  IBS(40,3),IBS2(40,3),SI(40,3),SF(40,3),FSPOF(40,3),PHIDP(40),   CRS10610
     3  THEDP(40),PSIDP(40),FSPBAR(40,3),FSPBA2(40,3),XLNGTH(3),XC(6),  CRS10620
     4  XDP(40),YDP(40),ZDP(40),FM3(6,6,80),VEE2(6,80),VEEDOT(3,3)      CRS10630
      DIMENSION PDOT(40),QDOT(40),RDOT(40),N(480),N3(80,6),DVSIGN(6),   CRS10640
     1  XKS(4320),XKS3(9,6,80),XKI(4320),TITLE(10)                      CRS00180
      DIMENSION XLBAR2(40,3),ISP2(40,3),XMU2(40,3),XKE2(40,3),          CRS10660
     1  XK3(6,6,80),VMAX2(6,80)                                         CRS10670
      DIMENSION XOLD(40),YOLD(40),ZOLD(40),PHIOLD(40),THEOLD(40),       CRS10680
     1  PSIOLD(40),POLD(40),QOLD(40),ROLD(40),UOLD(40),VOLD(40),WOLD(40)CRS10690
      DIMENSION XXK(80),XXJ(80),XYK(80),XYJ(80),XZK(80),XZJ(80),        CRS10700
     1  XLK(80),XLJ(80),XMK(80),XMJ(80),XNK(80),XNJ(80)                 CRS10710
      DIMENSION DXIJ(80),DYIJ(80),DZIJ(80)                              CRS10720
      DIMENSION PIN(40),QIN(40),RIN(40),PINO(40),QINO(40),RINO(40),     CRS00230
     1  DPIN(40),DQIN(40),DRIN(40)                                      CRS00240
      DIMENSION DD(6),DPX(40),DPY(40),DPZ(40),DPL(40),DPM(40),DPN(40)   CRS00250
      DIMENSION C(6,80),CBAR(80),DXDA(6,80)                             CRS00280
      DIMENSION XACC(40),YACC(40),ZACC(40)
      DIMENSION SUMDF(6,80),TRUPT(80),IRUPT(80),JRUPT(80)
      DIMENSION TPEN(80),IPEN(80)
      DIMENSION IJPR(76)
      DIMENSION AITAJ(9)
      DIMENSION FSPOI(40,3),SA(40,3),SB(40,3)
      DIMENSION ORI(76)
      COMMON ORI
      COMMON FSPOI,SA,SB
      COMMON AITAJ
      COMMON XNBAR,XPBAR,YNBAR,YPBAR,ZNBAR,ZPBAR,TPEN
      COMMON SUMDF,TRUPT,DXDA,SC
      COMMON XACC,YACC,ZACC
      COMMON C,CBAR                                                     CRS13280
      COMMON DD,DPX,DPY,DPZ,DPL,DPM,DPN                                 CRS00300
      COMMON PIN,QIN,RIN,PINO,QINO,RINO,DPIN,DQIN,DRIN                  CRS13310
      COMMON DXIJ,DYIJ,DZIJ,ZG                                          CRS13320
      COMMON XXK,XXJ,XYK,XYJ,XZK,XZJ,XLK,XLJ,XMK,XMJ,XNK,XNJ            CRS13330
      COMMON XOLD,YOLD,ZOLD,PHIOLD,THEOLD,PSIOLD,POLD,QOLD,ROLD,UOLD,   CRS13340
     1  VOLD,WOLD,DT2,DTHALF                                            CRS13350
      COMMON PHI,THETA,PSI                                              CRS13360
      COMMON BIJ,PSIDOT,THEDOT,PHIDOT,CIJ,X,Y,Z,XIJ,YIJ,ZIJ,D,DF        CRS13370
      COMMON AI,AIDOT,AJ,AIJ,DX,DY,DZ,DPHI,DTHETA,DPSI,DVSIGN           CRS13380
      COMMON                      VEE,FMBAR,FM,XKS,XKI,VMAX             CRS00400
      COMMON XX,XY,XZ,XL,XM,XN,WGT,ALIFT,XC,P,Q,R,U,V,W                 CRS13400
      COMMON UDOT,VDOT,WDOT,XZI,YZI,ZI,HEZ,XI,XYI,HEX,YI,HEY,DELI       CRS13410
      COMMON PDOT,XI1,XI2,XI3,QDOT,XI5,XI4,RDOT,XI6,XDOT,YDOT,ZDOT      CRS13420
```

Figure 20. (Continued)

```
      COMMON          XLBAR,SF,FSPOF,XKE,FSPBAR,XMU,VEEDOT                  CRS00440
      COMMON XGDOT,YGDOT,ZGDOT,PPR,QPR,RPR,PHIPR,THEPR,PSIPR                CRS00360
      COMMON PHIDP,THEDP,PSIDP,XDP,YDP,ZDP,OAI,DELTAT,TMAX,TIME,TITLE       CRS13450
      COMMON PHIIJ,THEIJ,PSIIJ,XK,DIJ,XXLBAR,SI,XLNGTH,IP                   CRS00470
      COMMON NM,I,J,ILAST,ITABIJ,ITAB6,IJLIJ,IJKLIJ,IJKK,IJL,IG,JG,ITAB,CRS13470
     1 ITABD,IJKL,ITABLI,IPRINT,ITABLE,ILINES,NPR,IGS,IISP,ISP,IBS,N,NHCRS00490
      COMMON KRUPT,IRUPT,JRUPT
      COMMON INDP,IPEN,KPEN
      COMMON IJPR
      COMMON PLOT,ZAR,TMPLOT,IPLOT,IDPLOT,IPLSK,IPLC,JPLOT,NPLGT,ITPLOT
      EQUIVALENCE (XLBAR2(1,1),XLBAR(1,1)),(ISP2(1,1),ISP(1,1)),            CRS10900
     1 (XMU2(1,1),XMU(1,1)),(XKE2(1,1),XKE(1,1)),(XK3(1,1,1),XK(1)),        CRS10910
     2 (VMAX2(1,1),VMAX(1))                                                 CRS10920
      EQUIVALENCE (XKS(1),XKS3(1,1,1)),(XKI(1),XKI3(1,1,1)),                CRS10930
     1 (XKRIN(1,1,1),FMBAR(1)),(FM(1),FM3(1,1,1)),(VEE(1),VEE2(1,1))        CRS10940
      EQUIVALENCE (FMBAR(1),FMBAR3(1,1,1)),(N(1),N3(1,1)),(NN(1,1),         CRS10950
     1 NN2(1,1)),(FSPBAR(1,1),FSPBA2(1,1)),(IBS(1,1),IBS2(1,1))             CRS10960
      READ 100, TITLE                                                       CRS13540
  100 FORMAT(10A8)                                                          CRS13550
      READ 200,NM,IPRINT,ITABLE,DELTAT,TMAX                                 CRS13560
      IF(DELTAT) 17,17,18                                                   CRS11000
   17 NM = 0                                                                CRS11010
      GO TO 1000                                                            CRS11020
   18 CONTINUE                                                              CRS11030
   19 IF(NM) 1000,1000,16                                                   CRS11040
  200 FORMAT(3I3,2E12.0)                                                    CRS13570
  300 FORMAT(6E12.0)                                                        CRS13580
   16 IGS = 0                                                               CRS11070
C READ THE I,J,PHIIJ,THEIJ,PSIIJ                                            CRS13600
   15 READ 400, I,J,PHIIN,THEIN,PSIIN                                       CRS13610
  400 FORMAT(2I3,3E12.0)                                                    CRS13620
      IF(I) 50,50,20                                                        CRS13630
   20 IGS = IGS+1                                                           CRS13640
      IG(IGS) = I                                                           CRS13650
      JG(IGS) = J                                                           CRS13660
      PHIIJ(IGS) = PHIIN                                                    CRS13670
      THEIJ(IGS) = THEIN                                                    CRS13680
      PSIIJ(IGS) = PSIIN                                                    CRS13690
      GO TO 15                                                              CRS13700
C READ WEIGHTS                                                              CRS13710
   50 READ 300, (WGT(I),I=1,NM)                                             CRS13720
C READ MOMENTS AND INERTIA PRODUCTS                                         CRS13730
      READ 300, (XI(I),YI(I),ZI(I),XYI(I),YZI(I),XZI(I),I=1,NM)             CRS13740
C READ ANGULAR MOMENTUM COMPONENTS                                          CRS13750
      READ 300, (HEX(I),HEY(I),HEZ(I),I=1,NM)                               CRS13760
C READ AERODYNAMIC LIFTS                                                    CRS13770
      READ 300, (ALIFT(I),I=1,NM)                                           CRS13780
C READ IC DATA                                                              CRS13790
      READ 300, XGDOT,YGDOT,ZGDOT                                           CRS13800
      READ 300, PPR,QPR,RPR                                                 CRS13810
      READ 300, PHIPR,THEPR,PSIPR,ZG                                        CRS13820
      READ 300, (XDP(I),YDP(I),ZDP(I),I=1,NM)                               CRS13830
      READ 300, (PHIDP(I),THEDP(I),PSIDP(I),I=1,NM)                         CRS13840
      READ 300,((XLBAR2(I,K),K=1,3),I=1,NM)                                 CRS13850
      READ 500, ((ISP2(I,K),K=1,3),I=1,NM)                                  CRS13860
  500 FORMAT(24I3)                                                          CRS13870
      READ 300,((XMU2(I,K),K=1,3),I=1,NM)                                   CRS13880
      READ 300,((XKE2(I,K),K=1,3),I=1,NM)                                   CRS13890
      READ 300,(((XK3(L,K,IJ),L=1,6),K=1,6),IJ=1,IGS)                       CRS13900
      READ 300,((VMAX2(L,IJ),L=1,6),IJ=1,IGS)                               CRS13910
```

Figure 20. (Continued)

```
C READ CR(IJL) VS. ABS(VPRIME(IJL))                                     CRS13920
      READ 300, ((DXDA(L,IJ),L=1,6),IJ=1,IGS)
      READ 300,(((XKRIN(I,L,IJ),I=1,ITABLE),L=1,6),IJ=1,IGS)            CRS13960
      READ 300,((SI(I,K),SA(I,K),SB(I,K),SF(I,K),FSPOI(I,K),
     1 FSP2F(I,K),K=1,3),I=1,NM)
      READ 300, (CBAR(IJ),IJ=1,IGS)                                     CRS13980
C READ PLOT INDICATORS
      NPLOT = 0
      JM = NM
      DO 30 I = 1,25
      IF(I.EQ.13) JM = IGS
      READ 928, INBUF
  928 FORMAT(76I1)
      DO 40 J = 1,JM
      IF (NPLOT.EQ.150)  GO TO 30
      IF(INBUF(J).EQ.0) GO TO 40
      NPLOT = NPLOT+1
      IDPLOT(NPLOT) = I
      IPLOT(NPLOT) = J
   40 CONTINUE
   30 CONTINUE
      READ 301,INDP
  301 FORMAT(40I2)
      IF (INDP.EQ.0)  GO TO 65
      READ 300, XNBAR,XPBAR,YNBAR,YPBAR,ZNBAR,ZPBAR
   65 READ 928, IJPR
C IF WE KNOW HOW MANY PLOTS WE WANT, WE CAN FIGURE OUT HOWMANY POINTS
C PER PLOT WE CAN HAVE, ALTHO WE DON'T WANT MORE THAN 500, BECAUSE
C WE COULDN'T NOTICE THE RESOLUTION ANYWAY.THE REST OF THIS FIGURES
C OUT HOW OFTEN TO SAVE. A TRUNCATED ITPLOT WILL TRY TO SAVE TOO MUCH
C AND THEN WE WOULDN'T GET TO TMAX, BUT IF WE WOULD ALMOST GET THERE
C IT WILL NOT BE NOTICEABLE ON THE PLOT.
      IF (NPLOT.EQ.0)  GO TO 60
   70 IP = 30000/NPLOT
      IF(IP.GT.500) IP = 500
      FITER = TMAX/DELTAT+2.0
      ITPLOT = FITER/IP
      IF(ITPLOT.EQ.0) ITPLOT = 1
      IF(FITER/(IP*ITPLOT).GT.1.002) ITPLOT = ITPLOT+1
   60 CONTINUE
C*****PRINT OUT INPUT                                                   CRS11610
  900 FORMAT ( '1',10A8)                                                CRS11620
  901 FORMAT ( ' NM,IPRINT,ITABLE,DELTAT,TMAX')                         CRS11630
  902 FORMAT ( 1X,3I5,1P2E15.5)                                         CRS11640
  903 FORMAT ( ' I,J,PHIIJ,THEIJ,PSIIJ' )                               CRS11650
  904 FORMAT ( 1X,2I5,1P3E15.5)                                         CRS11660
  905 FORMAT ( ' WGT' )                                                 CRS11670
  906 FORMAT ( 1X,1P6E15.5)                                             CRS11680
  907 FORMAT ( ' I,XI(I),YI(I),ZI(I),XYI(I),YZI(I),XZI(I)' )            CRS11690
  908 FORMAT ( 1X,I5,1P6E15.5)                                          CRS11700
  909 FORMAT ( ' I,HEX(I),HEY(I),HEZ(I)' )                              CRS11710
  910 FORMAT(1X,I5,1P3E15.5)                                            CRS11720
  911 FORMAT ( ' ALIFT' )                                               CRS11730
  912 FORMAT ( ' XGDOT,YGDOT,ZGDOT' )                                   CRS11740
  913 FORMAT ( ' PPR,QPR,RPR' )                                         CRS11750
  914 FORMAT ( ' PHIPR,THEPR,PSIPR')                                    CRS11760
  915 FORMAT ( ' I,XDP(I),YDP(I),ZDP(I)' )                              CRS11770
  916 FORMAT ( ' I,PHIDP(I),THEDP(I),PSIDP(I)' )                        CRS11780
  917 FORMAT ( ' I, LBAR (I,1), LBAR (I,2), LBAR (I,3)' )               CRS11790
  918 FORMAT ( ' I, SP (I,1), SP (I,2), SP (I,3)' )                     CRS11800
```

Figure 20. (Continued)

```
919 FORMAT ( ' I, MU (I,1), MU (I,2), MU (I,3)' )                       CRS11810
920 FORMAT ( ' I, KE (I,1), KE (I,2), KE (I,3)' )                       CRS11820
921 FORMAT (' IJ,K, XK(1,K,IJ),XK(2,K,IJ),XK(3,K,IJ),XK(4,K,IJ),XK(5,KCRS11830
   1,IJ),XK(6,K,IJ) ' )                                                 CRS11840
922 FORMAT (1X,2I5, 1P6E15.5  )                                         CRS11850
923 FORMAT ( ' I,  VMAX(1,I),VMAX(2,I),VMAX(3,I),VMAX(4,I),VMAX(5,I),VCRS11860
   1MAX(6,I) ' )                                                        CRS11870
924 FORMAT ( ' DX(L,IJ) FOR KR TABLES')                                 CRS11880
925 FORMAT ( ' IJ,L,KR(1,L,IJ),KR(2,L,IJ),KR(3,L,IJ),KR(4,L,IJ),KR(5,LCRS11890
   1,IJ),KR(6,L,IJ)' )                                                  CRS11900
926 FORMAT( ' I,K, SI(I,K),SA(I,K),SB(I,K),SF(I,K),FSPOI(I,K),
   1 FSPOF(I,K)' )
927 FORMAT(1X,4I5)                                                      CRS11920
    PRINT 900, TITLE                                                    CRS11930
    PRINT 901                                                           CRS11940
    PRINT 902, NM,IPRINT,ITABLE,DELTAT,TMAX                             CRS11950
    PRINT 903                                                           CRS11960
    PRINT 904, (IG(I),JG(I),PHIIJ(I),THEIJ(I),PSIIJ(I),I=1,IGS)         CRS11970
    PRINT 905                                                           CRS11980
    PRINT 906, (WGT(I),I=1,NM)                                          CRS11990
    PRINT 907                                                           CRS12000
    PRINT 908, (I,XI(I),YI(I),ZI(I),XYI(I),YZI(I),XZI(I),I=1,NM)        CRS12010
    PRINT 909                                                           CRS12020
    PRINT 910, (I,HEX(I),HEY(I),HEZ(I),I=1,NM)                          CRS12030
    PRINT 911                                                           CRS12040
    PRINT 906, (ALIFT(I),I=1,NM)                                        CRS12050
    PRINT 912                                                           CRS12060
    PRINT 906,  XGDOT,YGDOT,ZGDOT                                       CRS12070
    PRINT 913                                                           CRS12080
    PRINT 906,  PPR,QPR,RPR                                             CRS12090
    PRINT 914                                                           CRS12100
    PRINT 906,  PHIPR,THEPR,PSIPR                                       CRS12110
    PRINT 915                                                           CRS12120
    PRINT 910, (I,XDP(I),YDP(I),ZDP(I),I=1,NM)                          CRS12130
    PRINT 916                                                           CRS12140
    PRINT 910, (I,PHIDP(I),THEDP(I),PSIDP(I),I=1,NM)                    CRS12150
    PRINT 917                                                           CRS12160
    PRINT 910, (I,(XLBAR2(I,K),K=1,3),I=1,NM)                           CRS12170
    PRINT 918                                                           CRS12180
    PRINT 927, (I,(ISP2(I,K),K=1,3),I=1,NM)                             CRS12190
    PRINT 919                                                           CRS12200
    PRINT 910, (I,(XMU2(I,K),K=1,3),I=1,NM)                             CRS12210
    PRINT 920                                                           CRS12220
    PRINT 910, (I,(XKE2(I,K),K=1,3),I=1,NM)                             CRS12230
    PRINT 921                                                           CRS12240
    PRINT 922,((IJ,K,(XK3(L,K,IJ),L=1,6),K=1,6),IJ=1,IGS)               CRS12250
    PRINT 923                                                           CRS12260
    PRINT 908, (I,(VMAX2(L,I),L=1,6),I=1,IGS)                           CRS12270
    PRINT 924                                                           CRS12280
    PRINT 906, ((DXOA(L,IJ),L=1,6),IJ=1,IGS)                            CRS12290
    PRINT 925                                                           CRS12300
    PRINT 922, ((IJ,L,(XKRIN(I,L,IJ),I=1,ITABLE),L=1,6),IJ=1,IGS)       CRS12310
    PRINT 926                                                           CRS12320
    PRINT 922,((I,K,SI(I,K),SA(I,K),SB(I,K),SF(I,K),FSPOI(I,K),
   1 FSPOF(I,K),K=1,3),I=1,NM)
    PRINT 931
931 FORMAT( ' I,J,CBAR(J')
    PRINT 929, (IG(I),JG(I),CBAR(I),I=1,IGS)
929 FORMAT( 1X,2I5,1PE15.5)
    IF (INDP.EQ.0)  GO TO 1000
    PRINT 930
930 FORMAT( ' >,XNBAR,XPBAR,YNBAR,YPBAR,ZNBAR,ZPBAR' )
    PRINT 908,INDP,XNBAR,XPBAR,YNBAR,YPBAR,ZNBAR,ZPBAR
1000 RETURN                                                             CRS12340
    END                                                                 CRS14000
```

Figure 20. (Continued)

```
      SUBROUTINE IC                                                     CRS14010
      IMPLICIT REAL*8 (A-H,O-Z)
      REAL*4 PLOT(30000),ZAR,TMPLOT(500)
      DIMENSION SC(40,3),ZAR(200),IPLOT(150),IDPLOT(150)
      DIMENSION IG(80),JG(80),PHIIJ(80),THEIJ(80),PSIIJ(80),WGT(40),    CRS12380
     1  XI(40),YI(40),ZI(40),XYI(40),YZI(40),XZI(40),HEX(40),HEY(40),   CRS12390
     2  HEZ(40),ALIFT(40),X(40),Y(40),Z(40),PHI(40),THETA(40),PSI(40),  CRS12400
     3  U(40),V(40),W(40),P(40),Q(40),R(40),XDOT(40),YDOT(40),ZDOT(40), CRS12410
     4  PHIDOT(40),THEDOT(40),PSIDOT(40),UDOT(40),VDOT(40),WDOT(40)     CRS12420
      DIMENSION AIJ(9),AI(9),AJ(9),AIDOT(9),DX(40),DY(40),DZ(40),       CRS12430
     1  DPHI(40),DTHETA(40),DPSI(40),D(6),DF(6),XX(40),XY(40),XZ(40),   CRS12440
     2  XL(40),XM(40),XN(40),DELI(40),XI1(40),XI2(40),XI3(40),          CRS12450
     3  XI4(40),XI5(40),XI6(40),XK(2880),FMBAR(2880),FMBAR3(6,6,80),    CRS12460
     4  FM(2880),XKRIN(10,6,80),VEE(480),VMAX(480),NN(40,3),NN2(40,3)   CRS12470
      DIMENSION XKI3(9,6,80),BIJ(360),CIJ(360),DIJ(720),XLBAR(40,3),    CRS12480
     1  XXLBAR(3),ISP(40,3),IISP(3),XMU(40,3),XKE(40,3),OAI(360),       CRS12490
     2  IBS(40,3),IBS2(40,3),SI(40,3),SF(40,3),FSPOF(40,3),PHIDP(40),   CRS12500
     3  THEDP(40),PSIDP(40),FSPBAR(40,3),FSPBA2(40,3),XLNGTH(3),XC(6),  CRS12510
     4  XDP(40),YDP(40),ZDP(40),FM3(6,6,80),VEE2(6,80),VEEDOT(3,3)      CRS12520
      DIMENSION PDOT(40),QDOT(40),RDOT(40),N(480),N3(80,6),DVSIGN(6),   CRS12530
     1  XKS(4320),XKS3(9,6,80),XKI(4320),TITLE(10)                      CRS00180
      DIMENSION ABARPR(3,3),APR(3,3),XPPP(3),ANGDPR(3),DPR(3,3),        CRS12550
     1  AIDP(3,3),AIC(3,3),VIP(3),XV(3),ADPR(3,3),VJP(40,3)             CRS12560
      DIMENSION ISP2(40,3),XLBAR2(40,3)                                 CRS12570
      DIMENSION XOLD(40),YOLD(40),ZOLD(40),PHIOLD(40),THEOLD(40),       CRS12580
     1  PSIOLD(40),POLD(40),QOLD(40),ROLD(40),UOLD(40),VOLD(40),WOLD(40)CRS12590
      DIMENSION XXK(80),XXJ(80),XYK(80),XYJ(80),XZK(80),XZJ(80),        CRS12600
     1  XLK(80),XLJ(80),XMK(80),XMJ(80),XNK(80),XNJ(80)                 CRS12610
      DIMENSION DXIJ(80),DYIJ(80),DZIJ(80)                              CRS12620
      DIMENSION PIN(40),QIN(40),RIN(40),PINO(40),QINO(40),RINO(40),     CRS00230
     1  DPIN(40),DQIN(40),DRIN(40)                                      CRS00240
      DIMENSION DD(6),DPX(40),DPY(40),DPZ(40),DPL(40),DPM(40),DPN(40)   CRS00250
      DIMENSION C(6,80),CBAR(80),DXOA(6,80)                             CRS00280
      DIMENSION XACC(40),YACC(40),ZACC(40)
      DIMENSION SUMDF(6,80),TRUPT(80),IRUPT(80),JRUPT(80)
      DIMENSION TPEN(80),IPEN(80)
      DIMENSION IJPR(76)
      DIMENSION AITAJ(9)
      DIMENSION FSPOI(40,3),SA(40,3),SB(40,3)
      DIMENSION DRI(76)
      COMMON DRI
      COMMON FSPOI,SA,SB
      COMMON AITAJ
      COMMON XNBAR,XPBAR,YNBAR,YPBAR,ZNBAR,ZPBAR,TPEN
      COMMON SUMDF,TRUPT,DXOA,SC
      COMMON XACC,YACC,ZACC
      COMMON C,CBAR                                                     CRS14330
      COMMON DD,DPX,DPY,DPZ,DPL,DPM,DPN                                 CRS00300
      COMMON PIN,QIN,RIN,PINO,QINO,RINO,DPIN,DQIN,DRIN                  CRS14360
      COMMON DXIJ,DYIJ,DZIJ,ZG                                          CRS14370
      COMMON XXK,XXJ,XYK,XYJ,XZK,XZJ,XLK,XLJ,XMK,XMJ,XNK,XNJ            CRS14380
      COMMON XOLD,YOLD,ZOLD,PHIOLD,THEOLD,PSIOLD,POLD,QOLD,ROLD,UOLD,   CRS14390
     1  VOLD,WOLD,DT2,DTHALF                                            CRS14400
      COMMON PHI,THETA,PSI                                              CRS14410
      COMMON BIJ,PSIDOT,THEDOT,PHIDOT,CIJ,X,Y,Z,XIJ,YIJ,ZIJ,D,DF        CRS14420
      COMMON AI,AIDOT,AJ,AIJ,DX,DY,DZ,DPHI,DTHETA,DPSI,DVSIGN           CRS14430
      COMMON                     VEE,FMBAR,FM,XKS,XKI,VMAX              CRS00400
      COMMON XX,XY,XZ,XL,XM,XN,WGT,ALIFT,XC,P,Q,R,U,V,W                 CRS14450
      COMMON UDOT,VDOT,WDOT,XZI,YZI,ZI,HEZ,XI,XYI,HEX,YI,HEY,DELI       CRS14460
      COMMON PDOT,XI1,XI2,XI3,QDOT,XI5,XI4,RDOT,XI6,XDOT,YDOT,ZDOT      CRS14470
```

Figure 20. (Continued)

```
      COMMON         XLBAR,SF,FSPOF,XKE,FSPBAR,XMU,VEEDOT               CRS00440
      COMMON XGDOT,YGDOT,ZGDOT,PPR,QPR,RPR,PHIPR,THEPR,PSIPR            CRS00360
      COMMON PHIDP,THEDP,PSIDP,XDP,YDP,ZDP,OAI,DELTAT,TMAX,TIME,TITLE   CRS14500
      COMMON PHIIJ,THEIJ,PSIIJ,XK,DIJ,XXLBAR,SI,XLNGYH,IP               CRS00470
      COMMON NM,I,J,ILAST,ITABIJ,ITAB6,IJLIJ,IJKLIJ,IJKK,IJL,IG,JG,ITAB,CRS14520
     1  ITABO,IJKL,ITABL1,IPRINT,ITABLE,ILINES,NPR,IGS,IISP,ISP,IBS,N,NNCRS00490
      COMMON KRUPT,IRUPT,JRUPT
      COMMON INDP,IPEN,KPEN
      COMMON IJPR
      COMMON PLOT,ZAR,TMPLOT,IPLOT,IDPLOT,IPLSW,IPLC,JPLOT,NPLOT,ITPLOT
      EQUIVALENCE (PPR,XMPR(1)),                                        CRS12800
     1  (PHIDPR,ANGDPR(1)),(THEDPR,ANGDPR(2)),(PSIDPR,ANGDPR(3))        CRS12810
      EQUIVALENCE (XKS(1),XKS3(1,1,1)),(XKI(1),XKI3(1,1,1)),            CRS12820
     1  (XKRIN(1,1,1),FMBAR(1)),(FM(1),FM3(1,1,1)),(VEE(1),VEE2(1,1))   CRS12830
      EQUIVALENCE (FMBAR(1),FMBAR3(1,1,1)),(N(1),N3(1,1)),(NN(1,1),     CRS12840
     1  NN2(1,1)),(FSPBAR(1,1),FSPBA2(1,1)),(IBS(1,1),IBS2(1,1))        CRS12850
      EQUIVALENCE (XLBAR2(1,1),XLBAR(1,1)),(ISP2(1,1),ISP(1,1))         CRS12860
      SIN(X) = DSIN(X)                                                  CRS12870
      COS(X) = DCOS(X)                                                  CRS12880
      SQRT(X) = DSQRT(X)                                                CRS12890
      ARSIN(X) = DARSIN(X)                                              CRS12900
      ATAN2(Y,X) = DATAN2(Y,X)                                          CRS12910
      WTOT = 0.0                                                        CRS14600
      DO 10 I = 1,NM                                                    CRS14610
   10 WTOT = WTOT+WGT(I)                                                CRS14620
      XGDP = 0.0                                                        CRS14630
      YGDP = 0.0                                                        CRS14640
      ZGDP = 0.0                                                        CRS14650
      DO 20 I = 1,NM                                                    CRS14660
      XGDP = XGDP+WGT(I)*XDP(I)                                         CRS14670
      YGDP = YGDP+WGT(I)*YDP(I)                                         CRS14680
   20 ZGDP = ZGDP+WGT(I)*ZDP(I)                                         CRS14690
      XGDP = XGDP/WTOT                                                  CRS14700
      YGDP = YGDP/WTOT                                                  CRS14710
      ZGDP = ZGDP/WTOT                                                  CRS14720
C APRIME AND ABARPRIME (3)                                              CRS14730
      CALL EULER(APR,PHIPR,THEPR,PSIPR)                                 CRS14740
      S1 = SIN(PHIPR)                                                   CRS14750
      C1 = COS(PHIPR)                                                   CRS14760
      S2 = SIN(THEPR)                                                   CRS14770
      C2 = COS(THEPR)                                                   CRS14780
C NOW ABARPRIME (4)                                                     CRS14790
      ABARPR(1,1) = 1.0                                                 CRS14800
      ABARPR(2,1) = 0.0                                                 CRS14810
      ABARPR(3,1) = 0.0                                                 CRS14820
      ABARPR(1,2) = S1*S2/C2                                            CRS14830
      ABARPR(2,2) = C1                                                  CRS14840
      ABARPR(3,2) = S1/C2                                               CRS14850
      ABARPR(1,3) = C1*S2/C2                                            CRS14860
      ABARPR(2,3) = -S1                                                 CRS14870
      ABARPR(3,3) = C1/C2                                               CRS14880
C ANGLE DOT PRIMES (6)                                                  CRS14890
      CALL MATVEC(ABARPR,XMPR,ANGDPR,0)                                 CRS14900
C D PRIME (7)                                                           CRS14910
      DPR(1,1) = 0.0                                                    CRS14920
      DPR(1,2) = THEDPR*S1-PSIDPR*C1*C2                                 CRS14930
      DPR(1,3) = THEDPR*C1+PSIDPR*S1*C2                                 CRS14940
      DPR(2,1) = -DPR(1,2)                                              CRS14950
      DPR(2,2) = 0.0                                                    CRS14960
      DPR(2,3) = -PHIDPR+PSIDPR*S2                                      CRS14970
```

Figure 20. (Continued)

```
      DPR(3,1) = -DPR(1,3)                                              CRS14980
      DPR(3,2) = -DPR(2,3)                                              CRS14990
      DPR(3,3) = 0.0                                                    CRS15000
C A DOT PRIME (8)                                                       CRS15010
      CALL MATMUL(APR,DPR,ADPR)                                         CRS15020
      ZCMAX = 0.0                                                       CRS15030
C LOOP A                                                                CRS15040
      DO 40 I = 1,NM                                                    CRS15050
C AI DOUBLE PRIME (9)                                                   CRS15060
      CALL EULER(AIDP,PHIDP(I),THEDP(I),PSIDP(I))                       CRS15070
C AI (10)                                                               CRS15080
      CALL MATMUL(APR,AIDP,AIC)                                         CRS15090
      THETA(I) = -ARSIN(AIC(3,1))                                       CRS13420
      CT = 1.0/COS(THETA(I))                                            CRS13430
      PHI(I) = ARSIN(AIC(3,2)*CT)                                       CRS13440
      PSI(I) = ARSIN(AIC(2,1)*CT)                                       CRS13450
C (12)                                                                  CRS15180
      VJP(I,1) = XGDP-XDP(I)                                            CRS15190
      VJP(I,2) = YGDP-YDP(I)                                            CRS15200
      VJP(I,3) = ZGDP-ZDP(I)                                            CRS15210
C LOOP B                                                                CRS15220
      DO 50 K = 1,3                                                     CRS15230
      IF(ISP2(I,K)) 60,50,60                                            CRS15240
   60 VC = AIC(3,K)*ZLBAR2(I,K)                                         CRS15250
      DO 70 L = 1,3                                                     CRS15260
   70 VC = VC+APR(3,L)*VJP(I,L)                                         CRS15270
      IF(VC-ZCMAX) 50,50,80                                             CRS15280
   80 ZCMAX = VC                                                        CRS15290
   50 CONTINUE                                                          CRS15300
C END OF LOOP A                                                         CRS15310
   40 CONTINUE                                                          CRS15320
      IF(ZG) 220,210,220                                                CRS15330
  210 ZG = -ZCMAX-.00100                                                CRS15340
C SEE IF PHI'', ETC. ARE ALL ZERO                                       CRS15350
  220 DO 100 I = 1,NM                                                   CRS15360
      IF(PHIDP(I)) 150,110,150                                          CRS15370
  110 IF(THEDP(I)) 150,120,150                                          CRS15380
  120 IF(PSIDP(I)) 150,100,150                                          CRS15390
  100 CONTINUE                                                          CRS15400
C IF WE GET HERE WE COMPUTE NEW THETA(I,J) AND PSI(I,J)                 CRS15410
      PI = 3.14159265358979324D0
      PI2 = .5D0*PI
      DO 200 IJ = 1,IGS                                                 CRS15430
      I = IG(IJ)                                                        CRS15440
      J = JG(IJ)                                                        CRS15450
      XIJP = VJP(J,1)-VJP(I,1)                                          CRS15460
      YIJP = VJP(J,2)-VJP(I,2)                                          CRS15470
      ZIJP = VJP(J,3)-VJP(I,3)                                          CRS15480
      IF(YIJP) 140,130,140                                              CRS15490
  130 IF(XIJP) 180,170,180                                              CRS15500
  180 PSIIJ(IJ) = 0.0                                                   CRS15510
      THEIJ(IJ) = -ATAN2(ZIJP,XIJP)                                     CRS13800
      GO TO 200                                                         CRS15530
  170 PSIIJ(IJ) = 0.0                                                   CRS15540
      THEIJ(IJ) = -PI2                                                  CRS15550
      IF(ZIJP) 160,200,200                                              CRS15560
  160 THEIJ(IJ) = PI2                                                   CRS15570
      GO TO 200                                                         CRS15580
  140 PSIIJ(IJ) = ATAN2(YIJP,XIJP)                                      CRS13870
      THEIJ(IJ) = -ATAN2(ZIJP,SQRT(XIJP*XIJP+YIJP*YIJP))                CRS13880
```

Figure 20. (Continued)

```
  200 CONTINUE                                                          CRS15610
C LOOPC                                                                 CRS15620
  150 DO 90 I = 1,NM                                                    CRS15630
      VIP(1) = VJP(I,1)                                                 CRS15640
      VIP(2) = VJP(I,2)                                                 CRS15650
      VIP(3) = VJP(I,3)                                                 CRS15660
C (14)                                                                  CRS15670
      CALL MATVEC(APR,VIP,XV,0)                                         CRS15680
      XV(3) = XV(3)+ZG                                                  CRS15690
      X(I) = XV(1)                                                      CRS15700
      Y(I) = XV(2)                                                      CRS15710
      Z(I) = XV(3)                                                      CRS15720
C (15)                                                                  CRS15730
      CALL MATVEC(ADPR,VIP,XV,0)                                        CRS15740
      XV(1) = XV(1)+XGDOT                                               CRS15750
      XV(2) = XV(2)+YGDOT                                               CRS15760
      XV(3) = XV(3)+ZGDOT                                               CRS15770
      XDOT(I) = XV(1)                                                   CRS15780
      YDOT(I) = XV(2)                                                   CRS15790
      ZDOT(I) = XV(3)                                                   CRS15800
C (16)                                                                  CRS15810
      CALL MATVEC(AIC,XV,VIP,1)                                         CRS15820
      U(I) = VIP(1)                                                     CRS15830
      V(I) = VIP(2)                                                     CRS15840
      W(I) = VIP(3)                                                     CRS15850
C (17)                                                                  CRS15860
      CALL MATVEC(AIOP,XMPR,VIP,1)                                      CRS15870
      P(I) = VIP(1)                                                     CRS15880
      Q(I) = VIP(2)                                                     CRS15890
      R(I) = VIP(3)                                                     CRS15900
C AIBAR (18)                                                            CRS15910
      S1 = SIN(PHI(I))                                                  CRS15920
      C1 = COS(PHI(I))                                                  CRS15930
      S2 = SIN(THETA(I))                                                CRS15940
      C2 = COS(THETA(I))                                                CRS15950
      ABARPR(1,2) = S1*S2/C2                                            CRS15960
      ABARPR(2,2) = C1                                                  CRS15970
      ABARPR(3,2) = S1/C2                                               CRS15980
      ABARPR(1,3) = C1*S2/C2                                            CRS15990
      ABARPR(2,3) = -S1                                                 CRS16000
      ABARPR(3,3) = C1/C2                                               CRS16010
C (19)                                                                  CRS16020
      CALL MATVEC(ABARPR,VIP,XV,0)                                      CRS16030
      PHIDOT(I) = XV(1)                                                 CRS16040
      THEDOT(I) = XV(2)                                                 CRS16050
      PSIDOT(I) = XV(3)                                                 CRS16060
C END LOOP C                                                            CRS16070
   90 CONTINUE                                                          CRS16080
      PRINT 301
  301 FORMAT(1H ,'IJ,THEIJ(IJ),PSIIJ(IJ)' )
      PRINT 300,(IJ,THEIJ(IJ),PSIIJ(IJ),IJ=1,IGS)
  300 FORMAT (1H ,I5,1P2E15.5)
      RETURN                                                            CRS16090
      END                                                               CRS16100
```

Figure 20. (Continued)

```
 SUBROUTINE PRINT                                                     CRS16110
 IMPLICIT REAL*8 (A-H,O-Z)
 REAL*4 PLOT(30000),ZAR,TMPLOT(500)
 DIMENSION SC(40,3),ZAR(200),IPLOT(150),IDPLOT(150)
 DIMENSION IG(80),JG(80),PHIIJ(80),THEIJ(80),PSIIJ(80),WGT(40),      CRS14410
1  XI(40),YI(40),ZI(40),XYI(40),YZI(40),XZI(40),HEX(40),HEY(40),     CRS14420
2  HEZ(40),ALIFT(40),X(40),Y(40),Z(40),PHI(40),THETA(40),PSI(40),    CRS14430
3  U(40),V(40),W(40),P(40),Q(40),R(40),XDOT(40),YDOT(40),ZDOT(40),   CRS14440
4  PHIDOT(40),THEDOT(40),PSIDOT(40),UDOT(40),VDOT(40),WDOT(40)       CRS14450
 DIMENSION AIJ(9),AI(9),AJ(9),AIDOT(9),DX(40),DY(40),DZ(40),         CRS14460
1  DPHI(40),DTHETA(40),DPSI(40),D(6),DF(6),XX(40),XY(40),XZ(40),     CRS14470
2  XL(40),XM(40),XN(40),DELI(40),XI1(40),XI2(40),XI3(40),            CRS14480
3  XI4(40),XI5(40),XI6(40),XK(2880),FMBAR(2880),FMBAR3(6,6,80),      CRS14490
4  FM(2880),XKRIN(10,6,80),VEE(480),VMAX(480),NN(40,3),NN2(40,3)     CRS14500
 DIMENSION XKI3(9,6,80),BIJ(360),CIJ(360),DIJ(720),XLBAR(40,3),      CRS14510
1  XXLBAR(3),ISP(40,3),IISP(3),XMU(40,3),XKF(40,3),DAI(360),         CRS14520
2  IBS(40,3),IBS2(40,3),SI(40,3),SF(40,3),FSPOF(40,3),PHIDP(40),     CRS14530
3  THEDP(40),PSIDP(40),FSPBAR(40,3),FSPBA2(40,3),XLNGTH(3),XC(6),    CRS14540
4  XDP(40),YDP(40),ZDP(40),FM3(6,6,80),VEE2(6,80),VEEDOT(3,3)        CRS14550
 DIMENSION PDOT(40),QDOT(40),RDOT(40),N(480),N3(80,6),DVSIGN(6),     CRS14560
1  XKS(4320),XKS3(9,6,80),XKI(4320),TITLE(10)                        CRS00180
 DIMENSION XOLD(40),YOLD(40),ZOLD(40),PHIOLD(40),THEOLD(40),         CRS14580
1  PSIOLD(40),POLD(40),QOLD(40),ROLD(40),UOLD(40),VOLD(40),WOLD(40)CRS14590
 DIMENSION XXK(80),XXJ(80),XYK(80),XYJ(80),XZK(80),XZJ(80),          CRS14600
1  XLK(80),XLJ(80),XMK(80),XMJ(80),XNK(80),XNJ(80)                   CRS14610
 DIMENSION DXIJ(80),DYIJ(80),DZIJ(80)                                CRS14620
 DIMENSION PIN(40),QIN(40),RIN(40),PINO(40),QINO(40),RINO(40),       CRS00230
1  DPIN(40),DQIN(40),DRIN(40)                                        CRS00240
 DIMENSION DD(6),DPX(40),DPY(40),DPZ(40),DPL(40),DPM(40),DPN(40)     CRS00250
 DIMENSION C(6,80),CBAR(80),DXDA(6,80)                               CRS00280
 DIMENSION XACC(40),YACC(40),ZACC(40)
 DIMENSION SUMDF(6,80),TRUPT(80),IRUPT(80),JRUPT(80)
 DIMENSION TPEN(80),IPEN(80)
 DIMENSION IJPR(76)
 DIMENSION AITAJ(9)
 DIMENSION FSPOI(40,3),SA(40,3),SB(40,3)
 DIMENSION DRI(76)
 COMMON DRI
 COMMON FSPOI,SA,SB
 COMMON AITAJ
 COMMON XNBAR,XPBAR,YNBAR,YPBAR,ZNBAR,ZPBAR,TPEN
 COMMON SUMDF,TRUPT,DXDA,SC
 COMMON XACC,YACC,ZACC
 COMMON C,CBAR                                                        CRS16400
 COMMON DD,DPX,DPY,DPZ,DPL,DPM,DPN                                    CRS00300
 COMMON PIN,QIN,RIN,PINO,QINO,RINO,DPIN,DQIN,DRIN                     CRS16430
 COMMON DXIJ,DYIJ,DZIJ,ZG                                             CRS16440
 COMMON XXK,XXJ,XYK,XYJ,XZK,XZJ,XLK,XLJ,XMK,XMJ,XNK,XNJ               CRS16450
 COMMON XOLD,YOLD,ZOLD,PHIOLD,THEOLD,PSIOLD,POLD,QOLD,ROLD,UOLD,      CRS16460
1  VOLD,WOLD,DT2,DTHALF                                               CRS16470
 COMMON PHI,THETA,PSI                                                 CRS16480
 COMMON BIJ,PSIDOT,THEDOT,PHIDOT,CIJ,X,Y,Z,XIJ,YIJ,ZIJ,D,DF           CRS16490
 COMMON AI,AIDOT,AJ,AIJ,DX,DY,DZ,DPHI,DTHETA,DPSI,DVSIGN              CRS16500
 COMMON                   VEE,FMBAR,FM,XKS,XKI,VMAX                   CRS00400
 COMMON XX,XY,XZ,XL,XM,XN,WGT,ALIFT,XC,P,Q,R,U,V,W                    CRS16520
 COMMON UDOT,VDOT,WDOT,XZI,YZI,ZI,HEZ,XI,XYI,HEX,YI,HEY,DELI          CRS16530
 COMMON PDOT,XI1,XI2,XI3,QDOT,XI5,XI4,RDOT,XI6,XDOT,YDOT,ZDOT       CRS16540
 COMMON             XLBAR,SF,FSPOF,XKF,FSPBAR,XMU,VEEDOT              CRS00440
 COMMON XGDOT,YGDOT,ZGDOT,PPR,QPR,RPR,PHIPR,THEPR,PSIPR               CRS00360
 COMMON PHIDP,THEDP,PSIDP,XDP,YDP,ZDP,DAI,DELTAT,TMAX,TIME,TITLE      CRS16570
```

Figure 20. (Continued)

```
      COMMON PHIIJ,THEIJ,PSIIJ,XK,DIJ,XXLBAR,SI,XLNGTH,IP                CRS00470
      COMMON NM,I,J,ILAST,ITABIJ,ITAB6,IJLIJ,IJKLIJ,IJKK,IJL,IG,JG,ITAB,CRS16590
     1  ITABD,IJKL,ITABL1,IPRINT,ITABLE,ILINES,NPR,IGS,IISP,ISP,IBS,N,NNCRS00490
      COMMON KRUPT,IRUPT,JRUPT
      COMMON INDP,IPEN,KPEN
      COMMON IJPR
      COMMON PLOT,ZAR,TKPLOT,IPLOT,IDPLOT,IPLSW,IPLC,JPLOT,NPLOT,ITPLOT
      EQUIVALENCE (XKS(1),XKS3(1,1,1)),(XKI(1),XKI3(1,1,1)),             CRS14800
     1  (XKRIN(1,1,1),FMBAR(1)),(FM(1),FM3(1,1,1)),(VEE(1),VEE2(1,1))    CRS14810
      EQUIVALENCE (FMBAR(1),FMBAR3(1,1,1)),(N(1),N3(1,1)),(NN(1,1),      CRS14820
     1  NN2(1,1)),(FSPBAR(1,1),FSPBA2(1,1)),(IBS(1,1),IBS2(1,1))         CRS14830
      ILINES = 60                                                        CRS14840
      IPL = 6                                                            CRS14850
      ITTL = 9
C FORCE NEW PAGE                                                         CRS16670
      NPR = 1000                                                         CRS16680
      DO 99 I = 1,NM                                                     CRS16690
      IF (ILINES-NPR-IPL) 10,20,20                                       CRS16700
   10 PRINT 100, TITLE                                                   CRS16710
  100 FORMAT(1H1,10A8,/)                                                 CRS16720
      PRINT 200, TIME                                                    CRS16730
  200 FORMAT(1H ,6HTIME =,F9.5,/)                                        CRS16740
      PRINT 300                                                          CRS16750
      PRINT 400                                                          CRS16760
      PRINT 500                                                          CRS16770
      PRINT 600                                                          CRS16780
      PRINT 900
  300 FORMAT(1H ,18X,1HX,14X,1HY,14X,1HZ,13X,3HPHI,11X,5HTHETA,          CRS16790
     1  11X,3HPSI)                                                       CRS16800
  400 FORMAT(1H ,17X,4HXDOT,11X,4HYDOT,11X,4HZDOT,10X,5HPHIDOT,          CRS16810
     1  8X,8HTHETADOT,8X,6HPSIDOT)                                       CRS16820
  500 FORMAT(1H ,18X,1HU,14X,1HV,14X,1HW,14X,1HP,14X,1HQ,14X,1HR)        CRS16830
  600 FORMAT(1H ,17X,4HUDOT,11X,4HVDOT,11X,4HWDOT,11X,4HPDOT,11X,        CRS16840
     1  4HQDOT,11X,4HRDOT)                                               CRS16850
  900 FORMAT (1H ,16X,6HXACCEL,9X,6HYACCEL,9X,5HZACCEL,/)
      NPR = ITTL                                                         CRS16860
   20 NPR = NPR+IPL                                                      CRS16880
      PRINT 700, I,X(I),Y(I),Z(I),PHI(I),THETA(I),PSI(I)                 CRS16890
      PRINT 800, XDOT(I),YDOT(I),ZDOT(I),PHIDOT(I),THEDOT(I),PSIDOT(I)   CRS16900
      PRINT 800, U(I),V(I),W(I),P(I),Q(I),R(I)                           CRS16910
      PRINT 800, UDOT(I),VDOT(I),WDOT(I),PDOT(I),QDOT(I),RDOT(I)         CRS16920
      PRINT 800, XACC(I),YACC(I),ZACC(I)
      PRINT 800                                                          CRS16930
  700 FORMAT(1H ,5HMASS ,I2,2X,1P6F15.5)                                 CRS16940
  800 FORMAT(1H ,9X,1P6E15.5)                                            CRS16950
   99 CONTINUE                                                           CRS16960
      PRINT 830
  830 FORMAT(1H ,'IG(IJ),JG(IJ),SUMDF(1,IJ),SUMDF(2,IJ),SUMDF(3,IJ),'
     1 'SUMDF(4,IJ),SUMDF(5,IJ),SUMDF(6,IJ)')
      PRINT 810,(IG(IJ),JG(IJ),(SUMDF(K,IJ),K=1,6),IJ=1,IGS)
      PRINT 831
  831 FORMAT(1H ,'IG(IJ),JG(IJ),VEE2(1,IJ),VEE2(2,IJ),VEE2(3,IJ),VEE2(4,
     1IJ),VEE2(5,IJ),VEE2(6,IJ)' )
      PRINT 810,(IG(IJ),JG(IJ),(VEE2(K,IJ),K=1,6),IJ=1,IGS)
  810 FORMAT (1H ,1X,I2,2X,I2,2X,1P6E15.5)
      PRINT 832
  832 FORMAT(1H ,'I,SC(I,1),SC(I,2),SC(I,3)' )
      DO 40 I = 1,NM
      DO 50 J = 1,3
      IF(ISP(I,J).NE.0) GO TO 60
```

Figure 20. (Continued)

```
   50 CONTINUE
      GO TO 60
   60 PRINT 820, I,(SC(I,J),J=1,3)
  820 FORMAT(1H ,I7,2X,1P3E15.3)
   40 CONTINUE
      ISET=0
      DO 70 I=1,76
      IF (IJPR(I).EQ.0)  GO TO 70
      IF (ISET.EQ.1)  GO TO 65
      PRINT 821
  821 FORMAT(1H //1X,'MASS',7X,'DRI')
      ISET=1
   65 PRINT 822, JG(I),DRI(I)
   70 CONTINUE
  822 FORMAT(1H ,1X,I2,3X,1PE15.5)
      RETURN                                                            CRS16970
      END                                                               CRS16980
      SUBROUTINE SAVE
      IMPLICIT REAL*8 (A-H,O-Z)                                         CRS00010
      REAL*4 PLOT(30000),ZAR,TMPLOT(500)
      DIMENSION SC(40,3),ZAR(200),IPLOT(150),IDPLOT(150)
      DIMENSION IG(80),JG(80),PHIIJ(80),THEIJ(80),PSIIJ(80),WGT(40),    CRS00020
     1  XI(40),YI(40),ZI(40),XYI(40),YZI(40),XZI(40),HEX(40),HEY(40),   CRS00030
     2  HEZ(40),ALIFT(40),X(40),Y(40),Z(40),PHI(40),THETA(40),PSI(40),  CRS00040
     3  U(40),V(40),W(40),P(40),Q(40),R(40),XDOT(40),YDOT(40),ZDOT(40), CRS00050
     4  PHIDOT(40),THEDOT(40),PSIDOT(40),UDOT(40),VDOT(40),WDOT(40)     CRS00060
      DIMENSION AIJ(9),AI(9),AJ(9),AIDOT(9),DX(40),DY(40),DZ(40),       CRS00070
     1  DPHI(40),DTHETA(40),DPSI(40),D(6),DF(6),XX(40 ,XY(40),XZ(40),   CRS00080
     2  XL(40),XM(40),XN(40),DELI(40),XI1(40),XI2(40),XI3(40),          CRS00090
     3  XI4(40),XI5(40),XI6(40),XK(2880),FMBAR(2880),FMBAR3(6,6,80),    CRS00100
     4  F4(2880),XKRIN(10,6,80),VEE(480),VMAX(480),NN(40,3),NN2(40,3)   CRS00110
      DIMENSION XK3(9,6,80),BIJ(360),CIJ(360),DIJ(720),XLBAR(40,3),     CRS00120
     1  XXLBAR(3),ISP(40,3),IISP(3),XMU(40,3),XKE(40,3),DAI(360),       CRS00130
     2  IBS(40,3),IBS2(40,3),SI(40,3),SF(40,3),FSPOF(40,3),PHIDP(40),   CRS00140
     3  THEDP(40),PSIDP(40),FSPBAR(40,3),FSPBA2(40,3),XLNGTH(3),XC(6),  CRS00150
     4  XDP(40),YDP(40),ZDP(40),FM3(6,6,80),VEE2(6,80),VEEDOT(3,3)      CRS00160
      DIMENSION PDOT(40),QDOT(40),RDOT(40),N(480),N3(80,6),DVSIGN(6),   CRS00170
     1  XKS(4320),XKS3(9,6,80),XKI(4320),TITLE(10)                      CRS00180
      DIMENSION XOLD(40),YOLD(40),ZOLD(40),PHIOLD(40),THEOLD(40),       CRS00190
     1  PSIOLD(40),POLD(40),QOLD(40),ROLD(40),UOLD(40),VOLD(40),WOLD(40)CRS00200
      DIMENSION XXK(80),XXJ(80),XYK(80),XYJ(80),XZK(80),XZJ(80),        CRS00210
     1  XLK(80),XLJ(80),XMK(80),XMJ(80),XNK(80),XNJ(80)                 CRS00220
      DIMENSION DXIJ(80),DYIJ(80),DZIJ(80)                              CRS00230
      DIMENSION PIN(40),QIN(40),RIN(40),PINO(40),QINO(40),RINO(40),     CRS00230
     1  DPIN(40),DQIN(40),DRIN(40)                                      CRS00240
      DIMENSION DD(6),DPX(40),DPY(40),DPZ(40),DPL(40),DPM(40),DPN(40)   CRS00250
      DIMENSION C(6,80),CBAR(80),DXDA(6,80)                             CRS00280
      DIMENSION XACC(40),YACC(40),ZACC(40)
      DIMENSION SUMDF(6,80),TRUPT(80),IRUPT(80),JRUPT(80)
      DIMENSION TPEN(80),IPEN(80)
      DIMENSION IJPR(76)
      DIMENSION AITAJ(9)
      DIMENSION FSPOI(40,3),SA(40,3),SB(40,3)
      DIMENSION DRI(76)
      COMMON DRI
      COMMON FSPOI,SA,SB
      COMMON AITAJ
      COMMON XNBAR,XPBAR,YNBAR,YPBAR,ZNBAR,ZPBAR,TPEN
      COMMON SUMDF,TRUPT,DXDA,SC
      COMMON XACC,YACC,ZACC
      COMMON C,CBAR                                                     CRS00290
      COMMON DD,DPX,DPY,DPZ,DPL,DPM,DPN                                 CRS00300
      COMMON PIN,QIN,RIN,PINO,QINO,RINO,DPIN,DQIN,DRIN,                 CRS00320
      COMMON DXIJ,DYIJ,DZIJ,ZG                                          CRS00330
      COMMON XXK,XXJ,XYK,XYJ,XZK,XZJ,XLK,XLJ,XMK,XMJ,XNK,XNJ            CRS00340
      COMMON XOLD,YOLD,ZOLD,PHIOLD,THEOLD,PSIOLD,POLD,QOLD,ROLD,UOLD,   CRS00350
     1  VOLD,WOLD,DT2,DTHALF,                                           CRS00360
      COMMON PHI,THETA,PSI                                              CRS00370
      COMMON BIJ,PSIDOT,THEDOT,PHIDOT,CIJ,X,Y,Z,XIJ,YIJ,ZIJ,D,DF        CRS00380
      COMMON AI,AIDOT,AJ,AIJ,DX,DY,DZ,DPHI,DTHETA,DPSI,DVSIGN           CRS00390
      COMMON                     VEE,FMBAR,FM,XKS,XKI,VMAX              CRS00400
      COMMON XX,XY,XZ,XL,XM,XN,WGT,ALIFT,XC,P,Q,R,U,V,W                 CRS00410
      COMMON UDOT,VDOT,WDOT,XZI,YZI,ZI,HEZ,XI,XYI,HEX,YI,HEY,DELI       CRS00420
      COMMON PDOT,XI1,XI2,XI3,QDOT,XI5,XI4,RDOT,XI6,XDOT,YDOT,ZDOT      CRS00430
      COMMON             XLBAR,SF,FSPOF,XKE,FSPBAR,XMU,VEEDOT           CRS00440
      COMMON XCDOT,YCDOT,ZCDOT,PPR,QPR,RPR,PHIPR,THEPR,PSIPR            CRS00360
      COMMON PHIDP,THEDP,PSIDP,XDP,YDP,ZDP,DAI,DELTAT,TMAX,TIME,TITLE   CRS00460
```

Figure 20. (Continued)

```
      COMMON PHIIJ,THEIJ,PSIIJ,XK,DIJ,XXLBAR,SI,XLNGTH,IP               CRS00470
      COMMON NN,I,J,ILAST,ITABIJ,ITAB6,IJLIJ,IJKLIJ,IJKK,IJL,IG,JG,ITAB,CRS00480
     1  ITABD,IJKL,ITABLI,IPRINT,ITABLE,ILINES,NPR,IGS,IISP,ISP,IBS,N,NNCRS00490
      COMMON KRUPT,IPUPT,JRUPT
      COMMON INDP,IPEN,KPEN
      COMMON IJPR
      COMMON PLOT,ZAR,TMPLOT,IPLOT,IDPLOT,IPLSW,IPLC,JPLOT,NPLOT,ITPLOT
      EQUIVALENCE (XXS(1),XKS3(1,1,1)),(XKI(1),XKI3(1,1,1)),            CRS00410
     1  (XKRIN(1,1,1),FMBAR(1)),(FM(1),FM3(1,1,1)),(VEE(1),VEE2(1,1))   CRS00420
      EQUIVALENCE (FMBAR(1),FMBAR3(1,1,1)),(N(1),N3(1,1)),(NN(1,1),     CRS00430
     1  NN2(1,1)),(FSPBAR(1,1),FSPBA2(1,1)),(IBS(1,1),IBS2(1,1))        CRS00440
      IPLC = 0
      JPLOT = JPLOT+1
      IF(JPLOT.GT.IP) RETURN
      TMPLOT(JPLOT) = TIME
      DO 30 I = 1,NPLOT
      IS = IPLOT(I)
      ID = IDPLOT(I)
      GO TO (1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,
     1     22,23,24,25), ID
    1 T = X(IS)
      GO TO 30
    2 T = Y(IS)
      GO TO 30
    3 T = Z(IS)
      GO TO 30
    4 T = XDOT(IS)
      GO TO 30
    5 T = YDOT(IS)
      GO TO 30
    6 T = ZDOT(IS)
      GO TO 30
    7 T = XACC(IS)
      GO TO 30
    8 T = YACC(IS)
      GO TO 30
    9 T = ZACC(IS)
      GO TO 30
   10 T = SC(IS,1)
      GO TO 30
   11 T = SC(IS,2)
      GO TO 30
   12 T = SC(IS,3)
      GO TO 30
   13 T = VEE2(1,IS)
      GO TO 30
   14 T = VEE2(2,IS)
      GO TO 30
   15 T = VEE2(3,IS)
      GO TO 30
   16 T = VEE2(4,IS)
      GO TO 30
   17 T = VEE2(5,IS)
      GO TO 30
   18 T = VEE2(6,IS)
      GO TO 30
   19 T = SUMDF(1,IS)
      GO TO 30
   20 T = SUMDF(2,IS)
      GO TO 30
   21 T = SUMDF(3,IS)
      GO TO 30
   22 T = SUMDF(4,IS)
      GO TO 30
   23 T = SUMDF(5,IS)
      GO TO 30
   24 T = SUMDF(6,IS)
      GO TO 30
   25 T=DRI(IS)
   30 PLOT(IP*(I-1)+JPLOT) = T
      RETURN
      END
```

Figure 20. (Continued)

```
      SUBROUTINE PRINTM(A,ID,ILINE)                                     CRS16990
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION A(3,3)                                                  CRS17000
      PRINT 100, ID,ILINE                                               CRS17010
  100 FORMAT(1H ,'MATRIX ',A4,' ON PAGE ',I3)                           CRS15230
      PRINT 200, ((A(I,J),J=1,3),I=1,3)                                 CRS17030
  200 FORMAT(1H ,1P3E20.10)                                             CRS17040
      RETURN                                                            CRS17050
      END                                                               CRS17060

      SUBROUTINE TOLP
      IMPLICIT REAL*8 (A-H,O-Z)                                         CRS00010
      REAL*4 PLOT(30000),ZAR,TMPLOT(500)
      REAL*4 DELX,DELY,DLX,DLY,XFMT,YFMT,YMIN,YMAX,XMIN,XMAX
      DIMENSION SC(40,3),ZAR(200),IYCHAR(3),LIT(3),NAMES(25),
     1   IPLOT(150),IDPLOT(150)
      DIMENSION IG(80),JG(80),PHIIJ(80),THEIJ(80),PSIIJ(80),WGT(40),    CRS00020
     1  XI(40),YI(40),ZI(40),XYI(40),YZI(40),XZI(40),HEX(40),HEY(40),   CRS00030
     2  HEZ(40),ALIFT(40),X(40),Y(40),Z(40),PHI(40),THETA(40),PSI(40),  CRS00040
     3  U(40),V(40),W(40),P(40),Q(40),R(40),XDOT(40),YDOT(40),ZDOT(40), CRS00050
     4  PHIDOT(40),THEDOT(40),PSIDOT(40),UDOT(40),VDOT(40),WDOT(40)     CRS00060
      DIMENSION AIJ(9),AI(9),AJ(9),AIDOT(9),DX(40),DY(40),DZ(40),       CRS00070
     1  DPHI(40),DTHETA(40),DPSI(40),D(6),DF(6),XX(40),XY(40),XZ(40),   CRS00080
     2  XL(40),XM(40),XN(40),DELI(40),XI1(40),XI2(40),XI3(40),          CRS00090
     3  XI4(40),XI5(40),XI6(40),XK(2880),FMBAR(2880),FMBAR3(6,6,80),    CRS00100
     4  FM(2880),XKRIN(10,6,80),VEE(480),VMAX(480),NN(40,3),NN2(40,3)   CRS00110
      DIMENSION XKI3(9,6,80),BIJ(360),CIJ(360),DIJ(720),XLBAR(40,3),    CRS00120
     1  XXLBAR(3),ISP(40,3),IISP(3),XMU(40,3),XKF(40,3),DAI(360),       CRS00130
     2  IBS(40,3),IBS2(40,3),SI(40,3),SF(40,3),FSPOF(40,3),PHIDP(40),   CRS00140
     3  THEDP(40),PSIDP(40),FSPBAR(40,3),FSPBA2(40,3),XLNGTH(3),XC(6),  CRS00150
     4  XDP(40),YDP(40),ZDP(40),FM3(6,6,80),VEE2(6,80),VEEDOT(3,3)      CRS00160
      DIMENSION PDOT(40),QDOT(40),RDOT(40),N(480),H3(80,6),DVSIGN(6),   CRS00170
     1  XKS(4320),XKS3(9,6,80),XKI(4320),TITLE(10)                      CRS00180
      DIMENSION XOLD(40),YOLD(40),ZOLD(40),PHIOLD(40),THEOLD(40),       CRS00190
     1  PSIOLD(40),POLD(40),QOLD(40),ROLD(40),UOLD(40),VOLD(40),WOLD(40)CRS00200
      DIMENSION XXK(80),XXJ(80),XYK(80),XYJ(80),XZK(80),XZJ(80),        CRS00210
     1  XLK(80),XLJ(80),XMK(80),XMJ(80),XNK(80),XNJ(80)                 CRS00220
      DIMENSION OXIJ(80),OYIJ(80),OZIJ(80)                              CRS00230
      DIMENSION PIN(40),QIN(40),RIN(40),PINO(40),QINO(40),RINO(40),     CRS00230
     1  DPIN(40),DQIN(40),DRIN(40)                                      CRS00240
      DIMENSION DD(6),DPX(40),DPY(40),DPZ(40),DPL(40),DPM(40),DPN(40)   CRS00250
      DIMENSION C(6,80),CBAR(80),DXDA(6,80)                             CRS00280
      DIMENSION XACC(40),YACC(40),ZACC(40)
      DIMENSION SUMDF(6,80),TRUPT(80),IRUPT(80),JRUPT(80)
      DIMENSION TPEN(80),IPEN(80)
      DIMENSION IJPR(76)
      DIMENSION AITAJ(9)
      DIMENSION FSPOI(40,3),SA(40,3),SB(40,3)
      DIMENSION DRI(76)
      COMMON DRI
      COMMON FSPOI,SA,SB
      COMMON AITAJ
      COMMON XNBAR,XPBAR,YNBAR,YPBAR,ZNBAR,ZPBAR,TPEN
      COMMON SUMDF,TRUPT,DXDA,SC
      COMMON XACC,YACC,ZACC
      COMMON C,CBAR                                                     CRS00290
      COMMON DD,DPX,DPY,DPZ,DPL,DPM,DPN                                 CRS00300
      COMMON PIN,QIN,RIN,PINO,QINO,RINO,DPIN,DQIN,DRIN                  CRS00320
      COMMON OXIJ,OYIJ,OZIJ,ZG                                          CRS00330
      COMMON XXK,XXJ,XYK,XYJ,XZK,XZJ,XLK,XLJ,XMK,XMJ,XNK,XNJ            CRS00340
      COMMON XOLD,YOLD,ZOLD,PHIOLD,THEOLD,PSIOLD,POLD,QOLD,ROLD,UOLD,   CRS00350
     1  VOLD,WOLD,DT2,DTHALF                                            CRS00360
      COMMON PHI,THETA,PSI                                              CRS00370
      COMMON BIJ,PSIDOT,THEDOT,PHIDOT,CIJ,X,Y,Z,XIJ,YIJ,ZIJ,D,DF        CRS00380
      COMMON AI,AIDOT,AJ,AIJ,DX,DY,DZ,DPHI,DTHETA,DPSI,DVSIGN           CRS00390
      COMMON                 VEE,FMBAR,FM,XKS,XKI,VMAX                  CRS00400
      COMMON XX,XY,XZ,XL,XM,XN,WGT,ALIFT,XC,P,Q,R,U,V,W                 CRS00410
      COMMON UDOT,VDOT,WDOT,XZI,YZI,ZI,HEZ,XI,XYI,HEX,YI,HEY,DELI       CRS00420
      COMMON PDOT,XI1,XI2,XI3,QDOT,XI5,XI4,RDOT,XI6,XDOT,YDOT,ZDOT      CRS00430
      COMMON          XLBAR,SF,FSPOF,XKF,FSPBAR,XMU,VEEDOT              CRS00440
```

Figure 20. (Continued)

```
      COMMON XGDOT,YGDOT,ZGDOT,PPR,QPR,RPR,PHIPR,THEPR,PSIPR              CRS00360
      COMMON PHIDP,THEDP,PSIDP,XDP,YDP,ZDP,DAI,DELTAT,TMAX,TIME,TITLE    CRS00460
      COMMON PHIIJ,THEIJ,PSIIJ,XK,DIJ,XXLBAR,SI,XLNGTH,IP                 CRS00470
      COMMON NM,I,J,ILAST,ITABIJ,ITAB6,IJLIJ,IJKLIJ,IJKK,IJL,IG,JG,ITAB,CRS00480
     1  ITABD,IJKL,ITABLI,IPRINT,ITABLE,ILINES,NPR,IGS,IISP,ISP,IBS,N,NNCRS00490
      COMMON KRUPT,IRUPT,JRUPT
      COMMON INDP,IPEN,KPEN
      COMMON IJPR
      COMMON PLOT,ZAR,TMPLOT,IPLOT,IDPLOT,IPLSW,IPLC,JPLOT,NPLOT,ITPLOT
      EQUIVALENCE (XKS(1),XKS3(1,1,1)),(XKI(1),XKI3(1,1,1)),              CRS00410
     1  (XKBIN(1,1,1),FMBAR(1)),(FM(1),FM3(1,1,1)),(VEE(1),VEE2(1,1))     CRS00420
      EQUIVALENCE (FMBAR(1),FMBAR3(1,1,1)),(N(1),N3(1,1)),(NN(1,1),       CRS00430
     1  NN2(1,1)),(FSPBAR(1,1),FSPBA2(1,1)),(IBS(1,1),IBS2(1,1))          CRS00440
      DATA LIT/'(   )',' (   ',',   )'/
      DATA NAMES/' X  ',' Y  ',' Z  ','XDOT','YDOT','ZDOT',
     1           ' AX ',' AY ',' AZ ',' S1 ',' S2 ',' S3 ',
     2           ' V1 ',' V2 ',' V3 ',' V4 ',' V5 ',' V6 ',
     3           ' F1 ',' F2 ',' F3 ',' F4 ',' F5 ',' F6 ',
     3           ' DRI'/
      IYCHAR(3) = LIT(3)
      IF(JPLOT.GT.IP) JPLOT = IP
      XMIN = TMPLOT(1)
      XMAX = TMPLOT(JPLOT)
      IF(XMIN.EQ.XMAX) RETURN
C IF 1ST TIME INITIALIZE
      IF(IPLSW.NE.0) GO TO 5
      IPLSW = 1
      CALL MODESG(ZAR,0)
      CALL SETSMG(ZAR,93,6.0)
      CALL SETSMG(ZAR,97,150.0)
      CALL SETSMG(ZAR,100,2.0)
    5 IYCHAR(2) = LIT(1)
      NY = 8
      DO 10 I = 1,NPLOT
      IF (IDPLOT(I).EQ.25)  GO TO 15
      IF(IDPLOT(I).LE.12) GO TO 20
      NY = 12
      IYCHAR(2) = LIT(2)
      CALL FMTSG(ZAR,1,4,0,IG(IPLOT(I)),IBUF)
      CALLGETCZZ(ZAR,IHOLD,3,IBUF)
      CALLPUTCZZ(ZAR,IHOLD,3,IYCHAR(2))
      CALLGETCZZ(ZAR,IHOLD,4,IBUF)
      CALLPUTCZZ(ZAR,IHOLD,4,IYCHAR(2))
      CALL FMTSG(ZAR,1,4,0,JG(IPLOT(I)),IBUF)
      CALLGETCZZ(ZAR,IHOLD,3,IBUF)
      CALLPUTCZZ(ZAR,IHOLD,2,IYCHAR(3))
      CALLGETCZZ(ZAR,IHOLD,4,IBUF)
      CALLPUTCZZ(ZAR,IHOLD,3,IYCHAR(3))
      GO TO 30
   15 CALL FMTSG(ZAR,1,4,0,JG(IPLOT(I)),IBUF)
      IYCHAR(2)=LIT(1)
      NY=8
      GO TO  25
   20 CALL FMTSG(ZAR,1,4,0,IPLOT(I),IBUF)
   25 CALLGETCZZ(ZAR,IHOLD,3,IBUF)
      CALLPUTCZZ(ZAR,IHOLD,2,IYCHAR(2))
      CALLGETCZZ(ZAR,IHOLD,4,IBUF)
      CALLPUTCZZ(ZAR,IHOLD,3,IYCHAR(2))
   30 IYCHAR(1) = NAMES(IDPLOT(I))
      YMIN = PLOT(IP*(I-1)+1)
```

Figure 20. (Continued)

```
      YMAX = YMIN
      DO 40 J = 2,JPLOT
      YMIN = AMIN1(YMIN,PLOT(IP*(I-1)+J))
   40 YMAX = AMAX1(YMAX,PLOT(IP*(I-1)+J))
      IF(YMIN.EQ.YMAX) GO TO 10
      CALL SUBJEG(ZAR,XMIN,YMIN,XMAX,YMAX)
      CALL SETUPG(ZAR,1,DELX,DELY,IXTH,JYTH,DLX,DLY,XFMT,YFMT)
      DO 60 J = 106,109
   60 ZAR(J) = 0.0
      CALL GRIDG(ZAR,DELX,DELY,IXTH,JYTH)
      CALL SETSMG(ZAR,45,1.0)
      CALL LABELG(ZAR,0,DLX,0,XFMT)
      CALL LABELG(ZAR,1,DLY,0,YFMT)
      CALL SETSMG(ZAR,45,1.5)
      CALL TITLEG(ZAR,14,14HTIME (SECONDS),NY,IYCHAR,70,TITLE)
      CALL LINESG(ZAR,JPLOT,YMPLOT,PLOT(IP*(I-1)+1))
C NEW FRAME
      CALL PAGEG(ZAR,0,1,1)
   10 CONTINUE
      RETURN
      END
```

Figure 20. (Continued)

TEST DATA

RECORDED DATA

The acceleration and strain gage data recorded on the Central Data System (CDS) are presented in Figures 21 through 46. The CDS sample is at a rate of 1500 per sec. This provides 5 samples per cycle for a 300-Hz signal. The list of acceleration channels is presented in Volume I, Table IX. Channels 61 and 62 represent the strain gage data near the leading edge of the forward and aft landing skid struts, respectively. The time of impact is zero (0) on the time scale. Positive times occur after impact.

100-CPS LOW-PASS FILTERED TEST DATA

Thirteen acceleration data channels were recorded on FM tape while the full complement of data was being recorded simultaneously in CDS. The channels that were recorded on tape are:

Channel No.	Identification
07	Pilot Seat Pan Vertical Acceleration
08	Pilot Seat Pan Lateral Acceleration
09	Copilot Seat Pan Vertical Acceleration
10	Copilot Seat Pan Lateral Acceleration
30	Copilot Floor Vertical Acceleration
31	Copilot Floor Lateral Acceleration
36	Passenger Floor Vertical Acceleration
40	Transmission Vertical Acceleration
41	Transmission Lateral Acceleration
42	Transmission Axial Acceleration
43	Engine Vertical Acceleration
44	Engine Lateral Acceleration
45	Engine Axial Acceleration

Figures 47 through 59 show the filtered data.

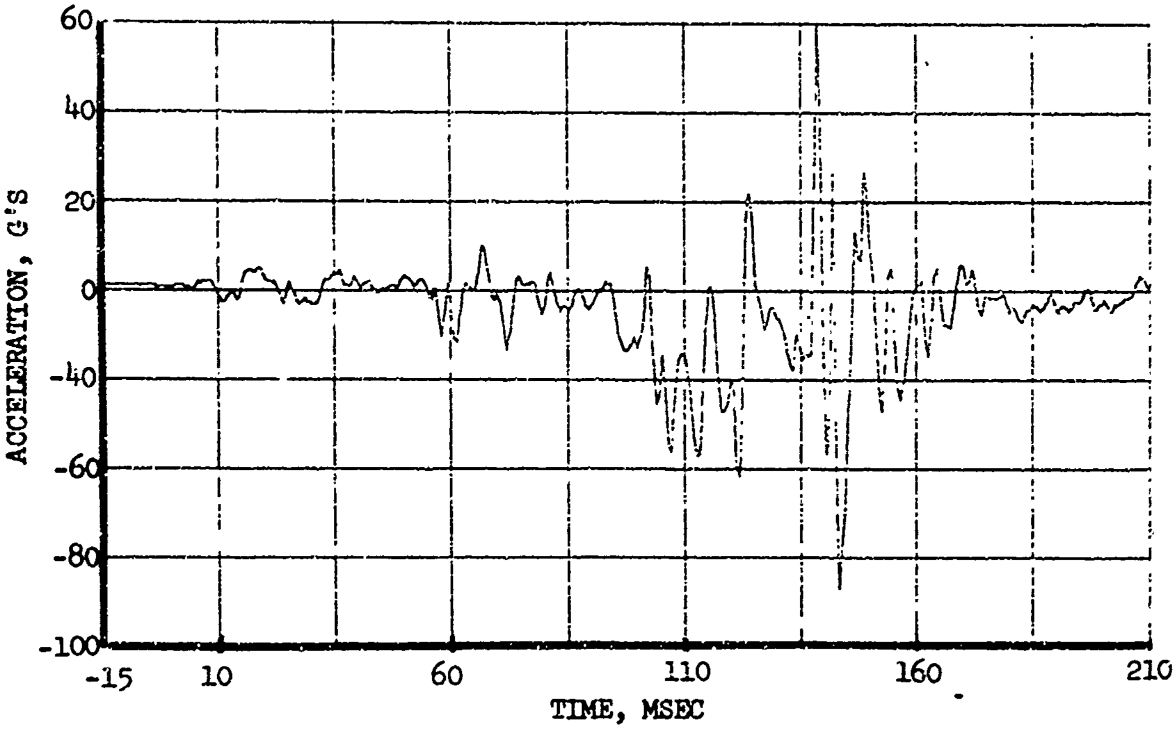


Figure 21. Recorded Time History, Pilot Seat Pan, Vertical Acceleration (Channel 07).

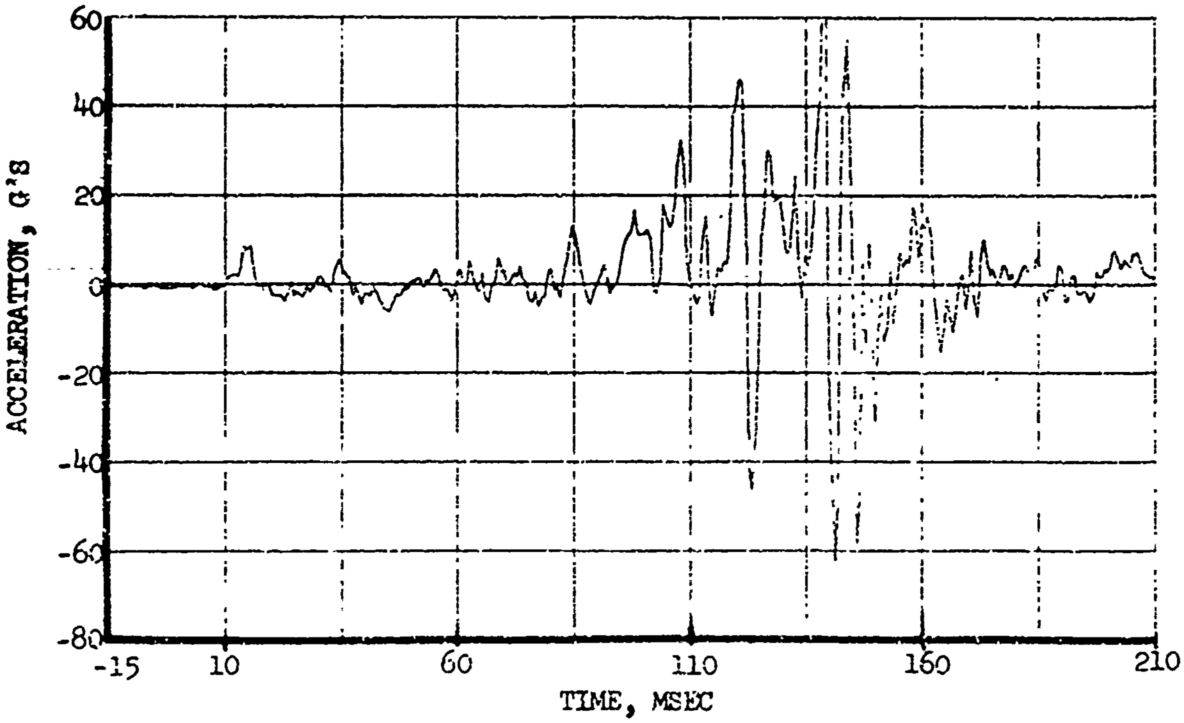


Figure 22. Recorded Time History, Pilot Seat Pan, Lateral Acceleration (Channel 08).

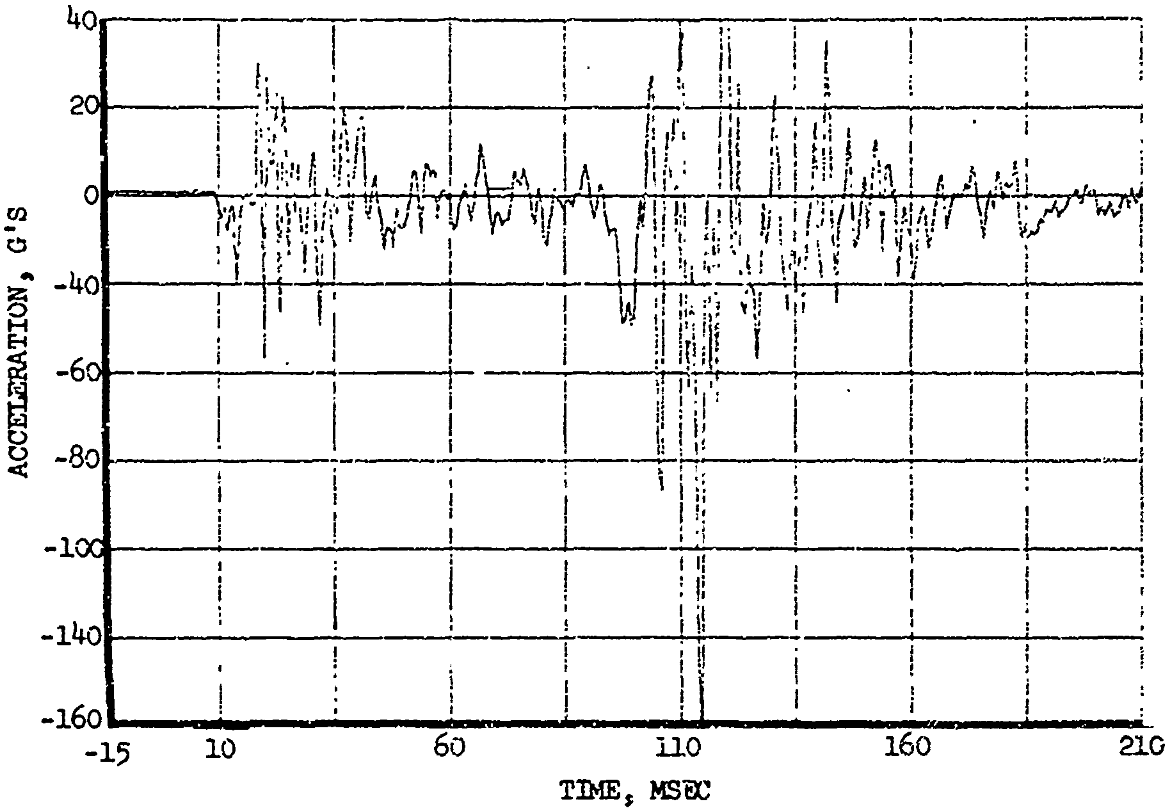


Figure 23. Recorded Time History, Copilot Seat Pan, Vertical Acceleration (Channel 09).

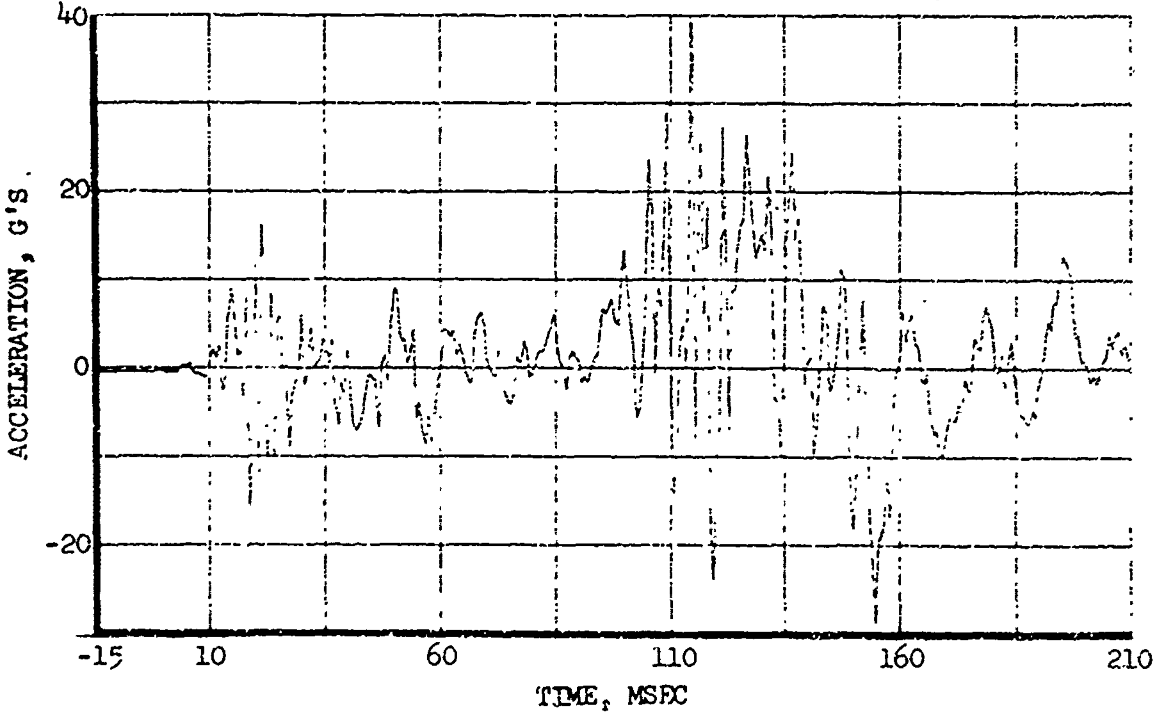


Figure 24. Recorded Time History, Copilot Seat Pan, Lateral Acceleration (Channel 10).

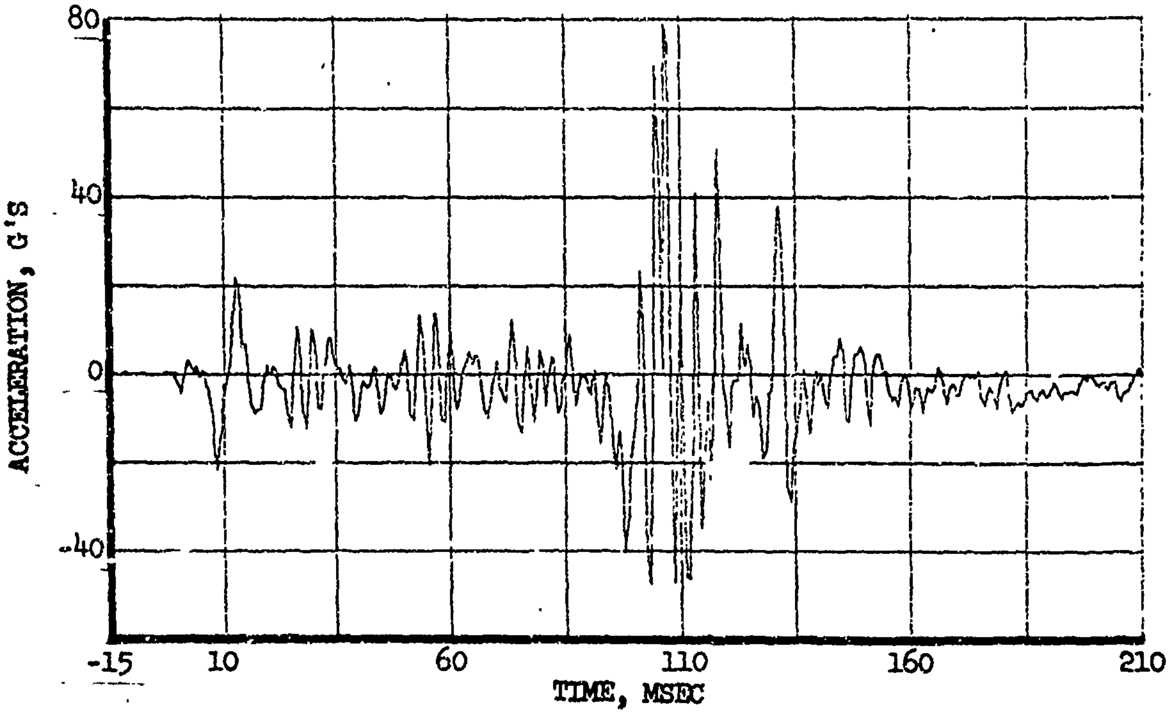


Figure 25. Recorded Time History, Floor Copilot Location, Vertical Acceleration (Channel 30).

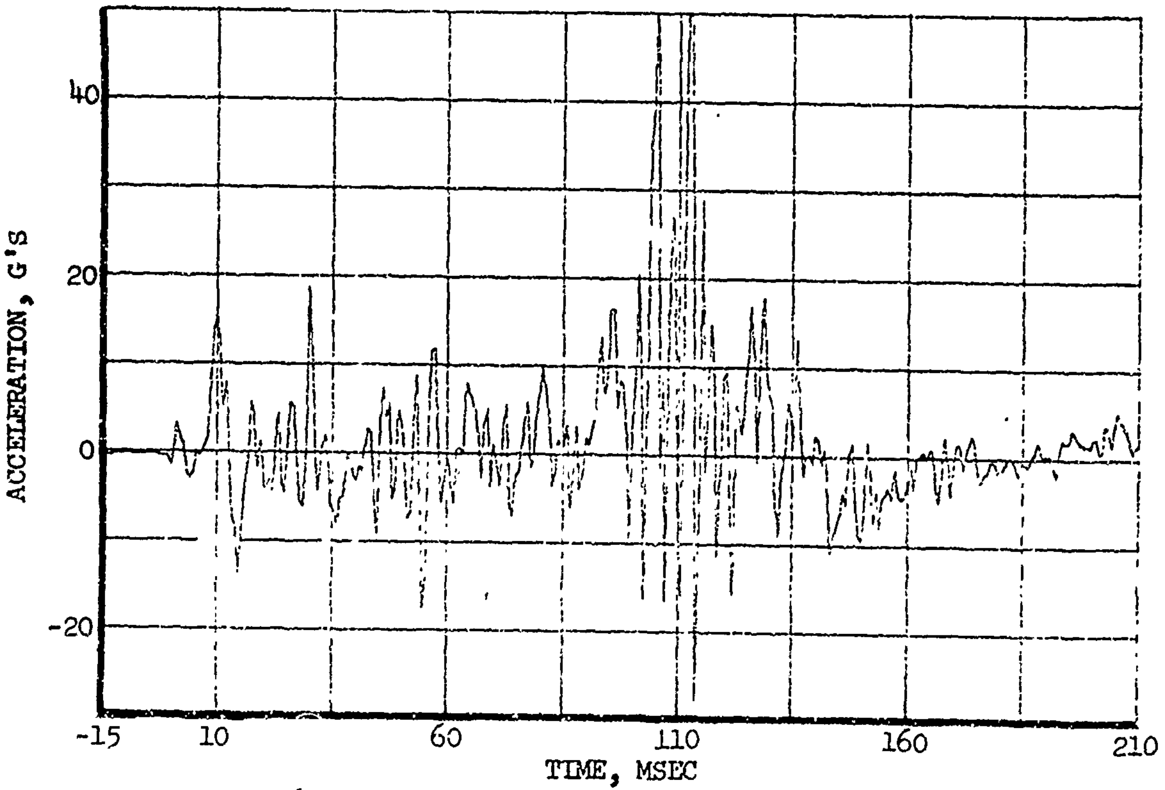


Figure 26. Recorded Time History, Floor Copilot Location, Lateral Acceleration (Channel 31).

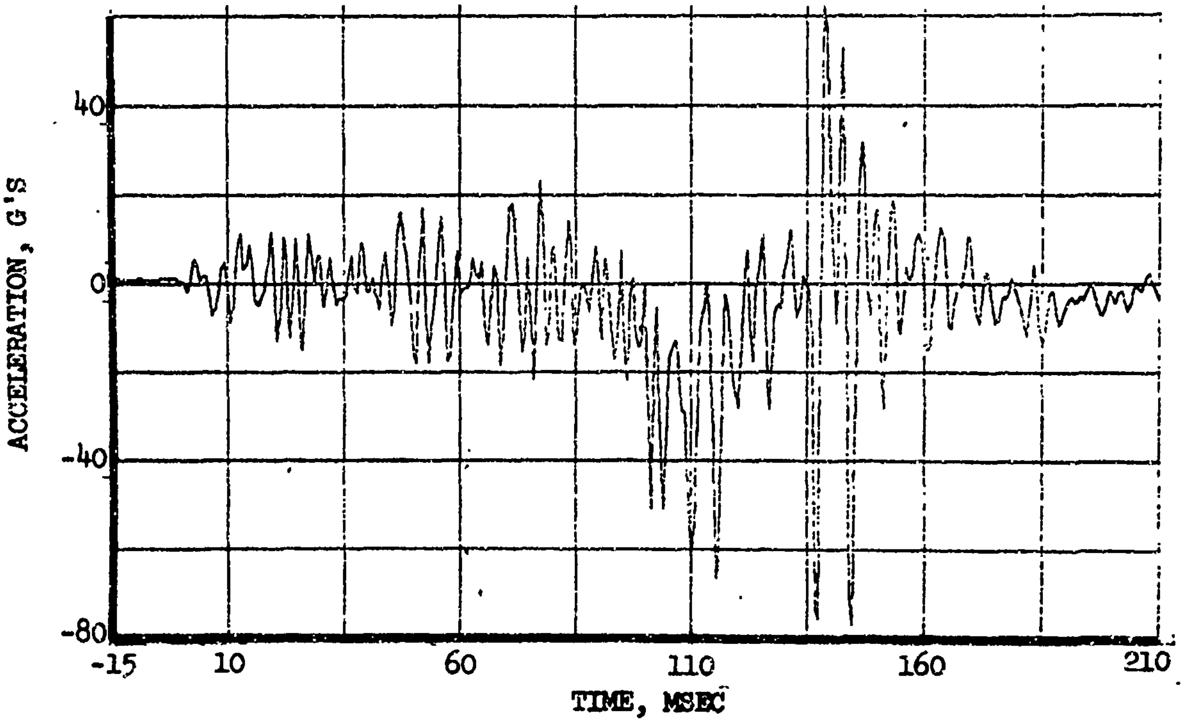


Figure 27. Recorded Time History, Floor Pilot Location, Vertical Acceleration (Channel 32).

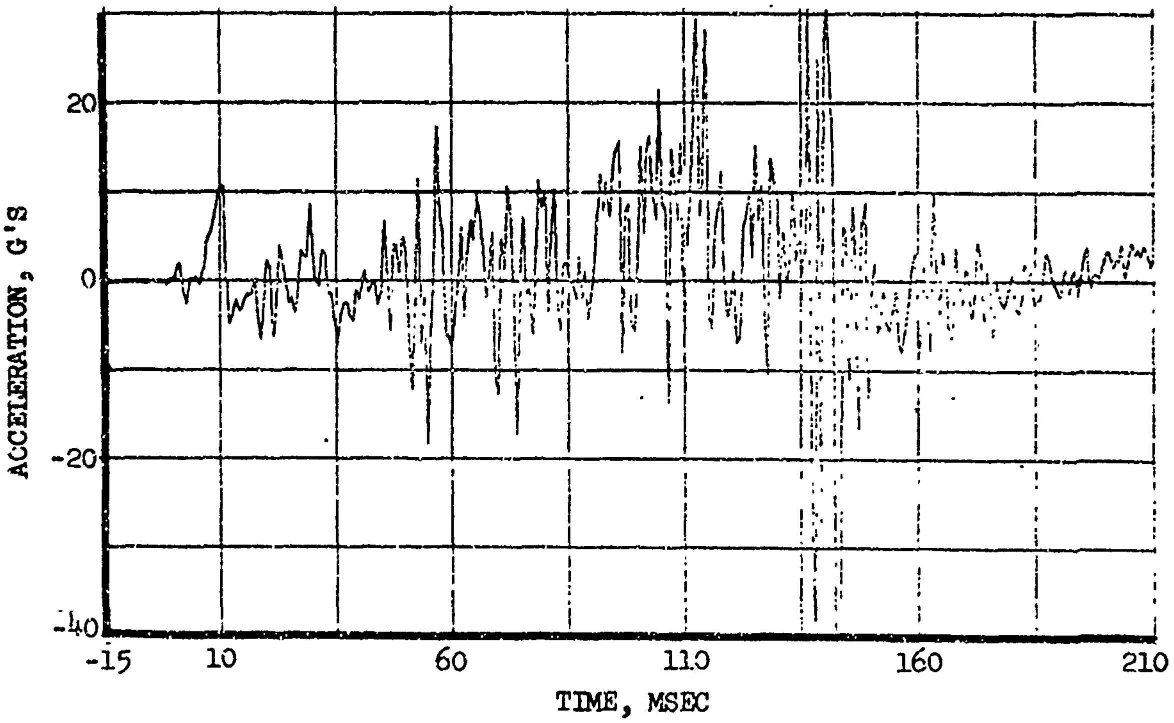


Figure 28. Recorded Time History, Floor Pilot Location, Lateral Acceleration (Channel 33).

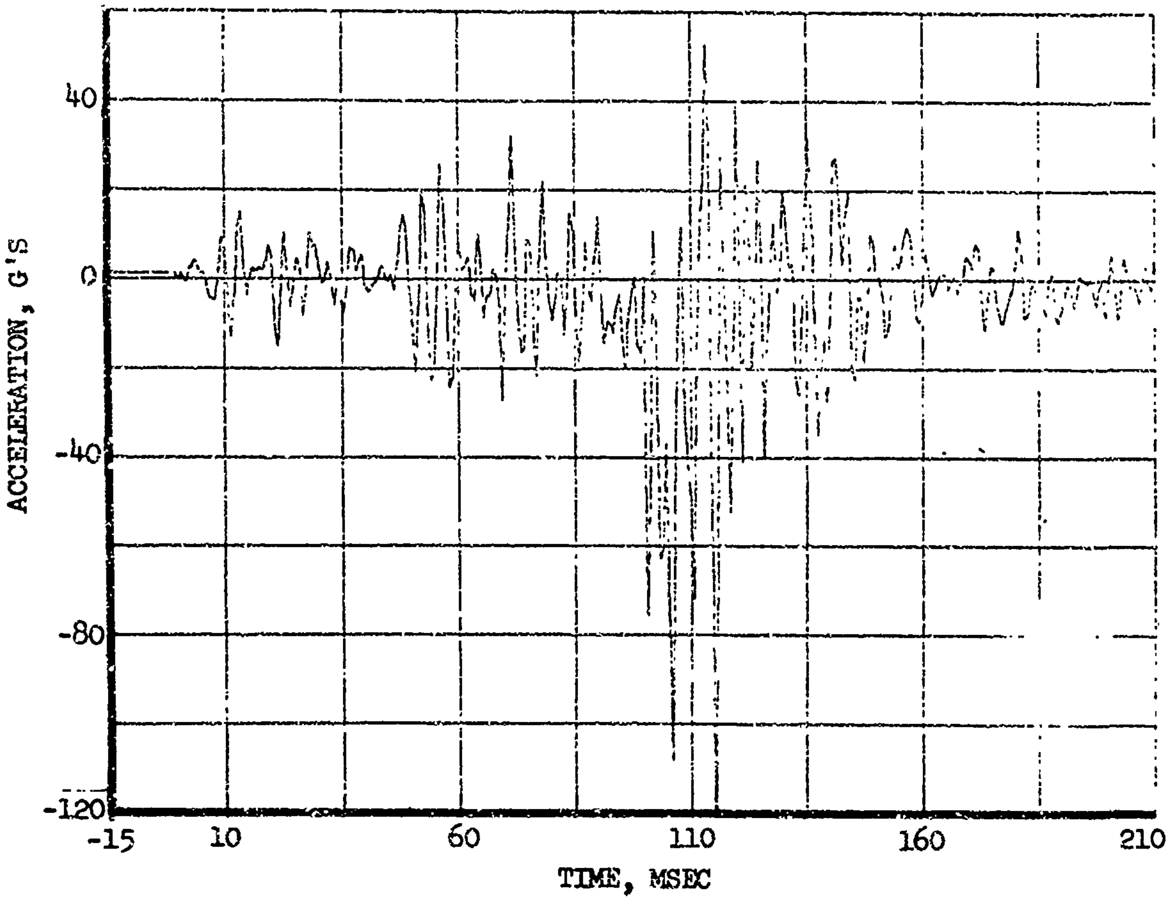


Figure 29. Recorded Time History, Cargo Floor Forward Right, Vertical Acceleration (Channel 34).

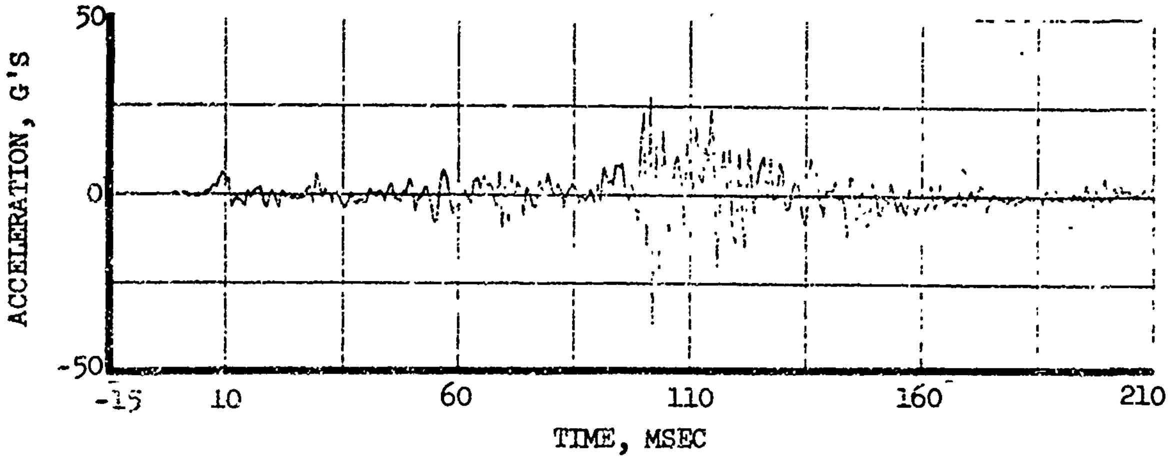


Figure 30. Recorded Time History, Cargo Floor Forward Right, Lateral Acceleration (Channel 35).

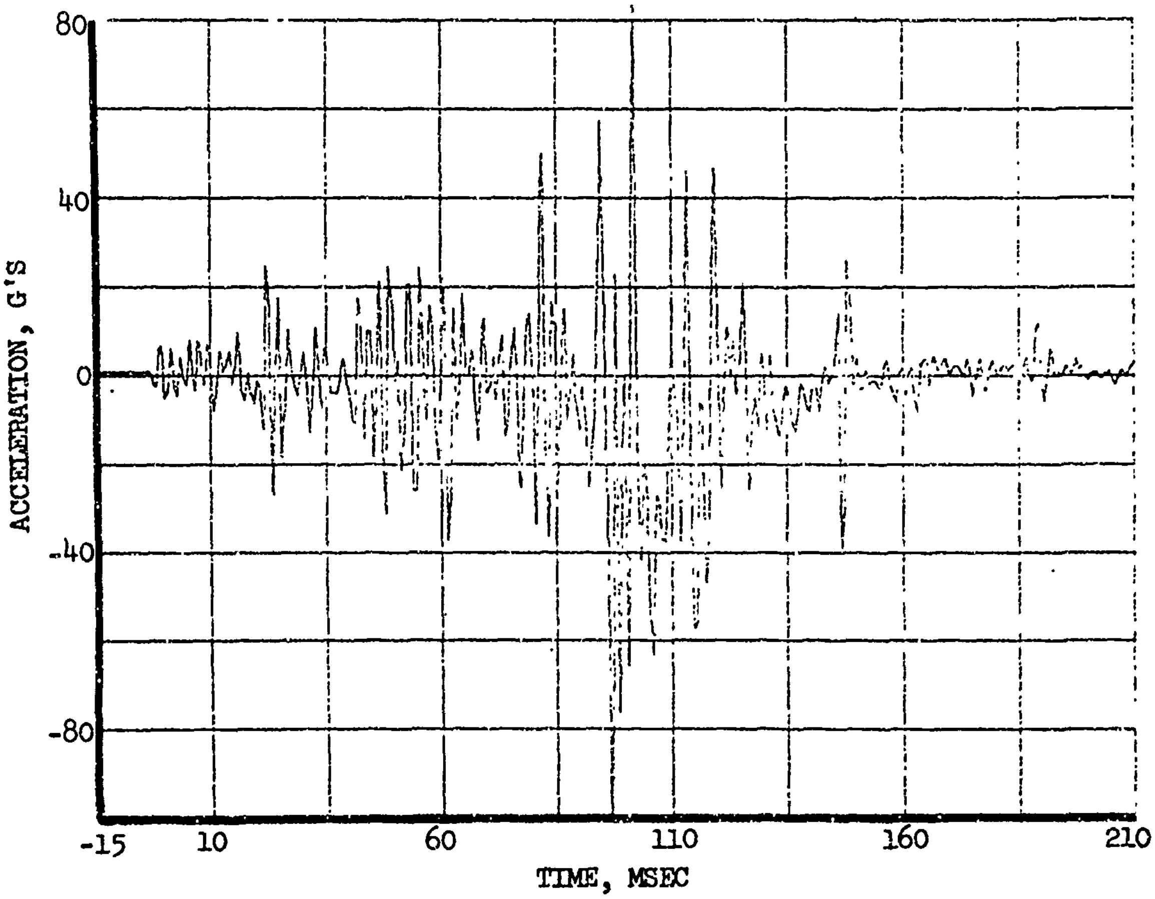


Figure 31. Recorded Time History, PAX Floor Rear Left, Vertical Acceleration (Channel 36).

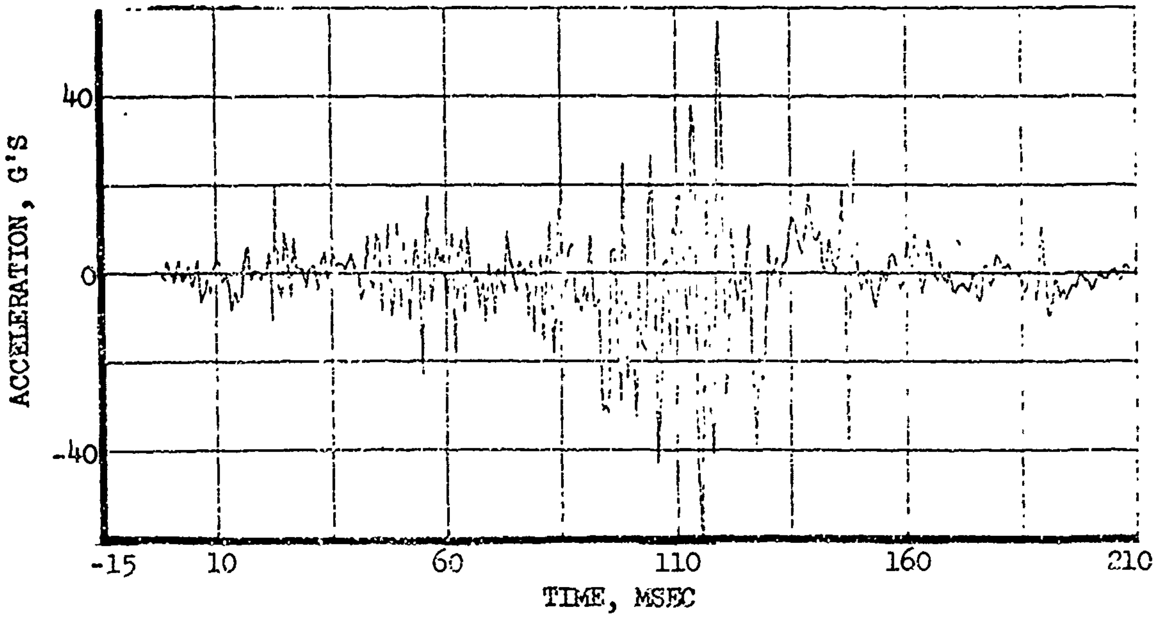


Figure 32. Recorded Time History, PAX Floor Rear Left, Lateral Acceleration (Channel 37).

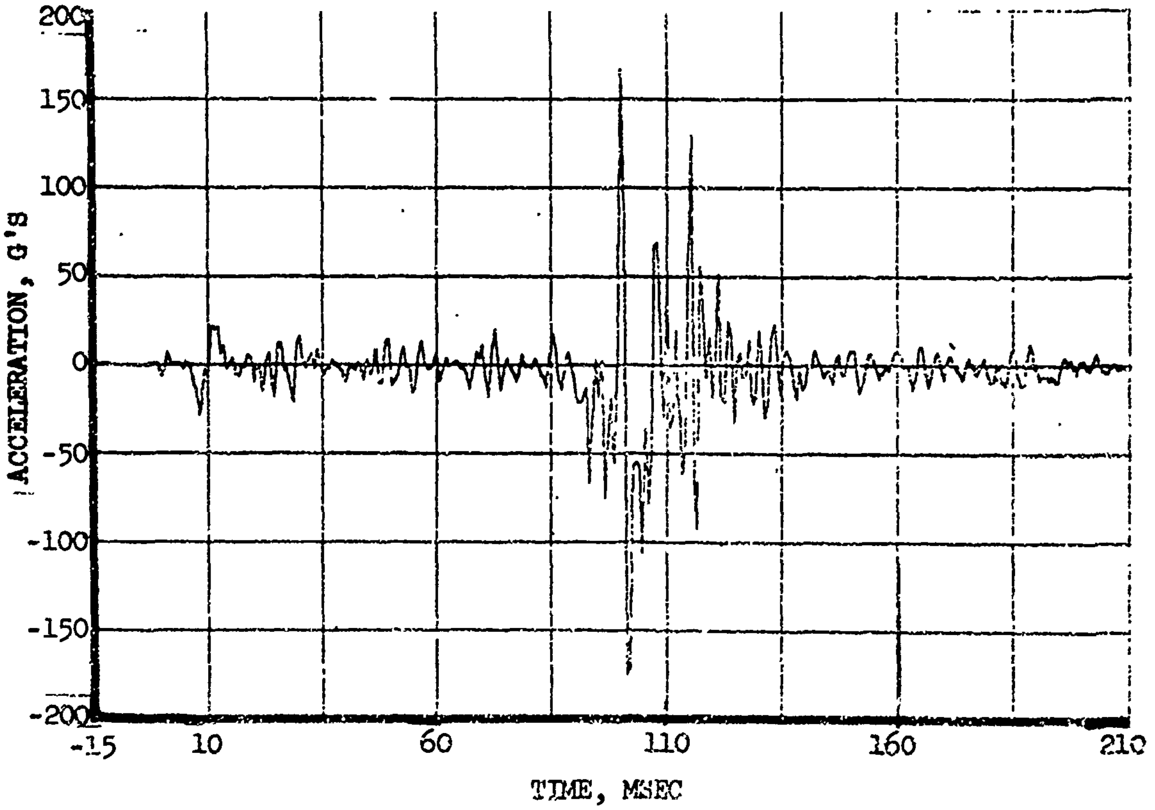


Figure 33. Recorded Time History, Cargo Floor Forward Left, Vertical Acceleration (Channel 38).

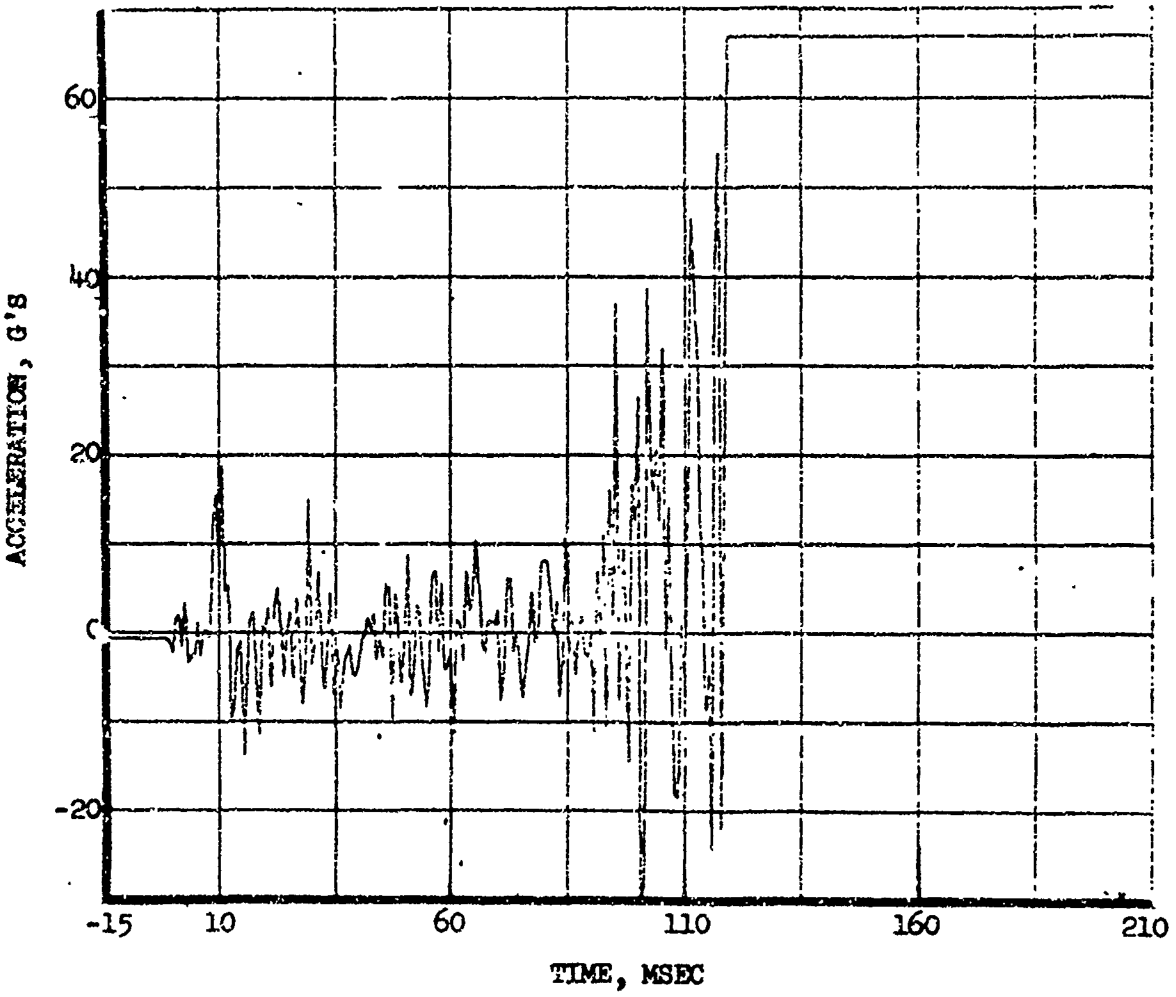


Figure 34. Recorded Time History, Cargo Floor Forward Left, Lateral Acceleration (Channel 39).

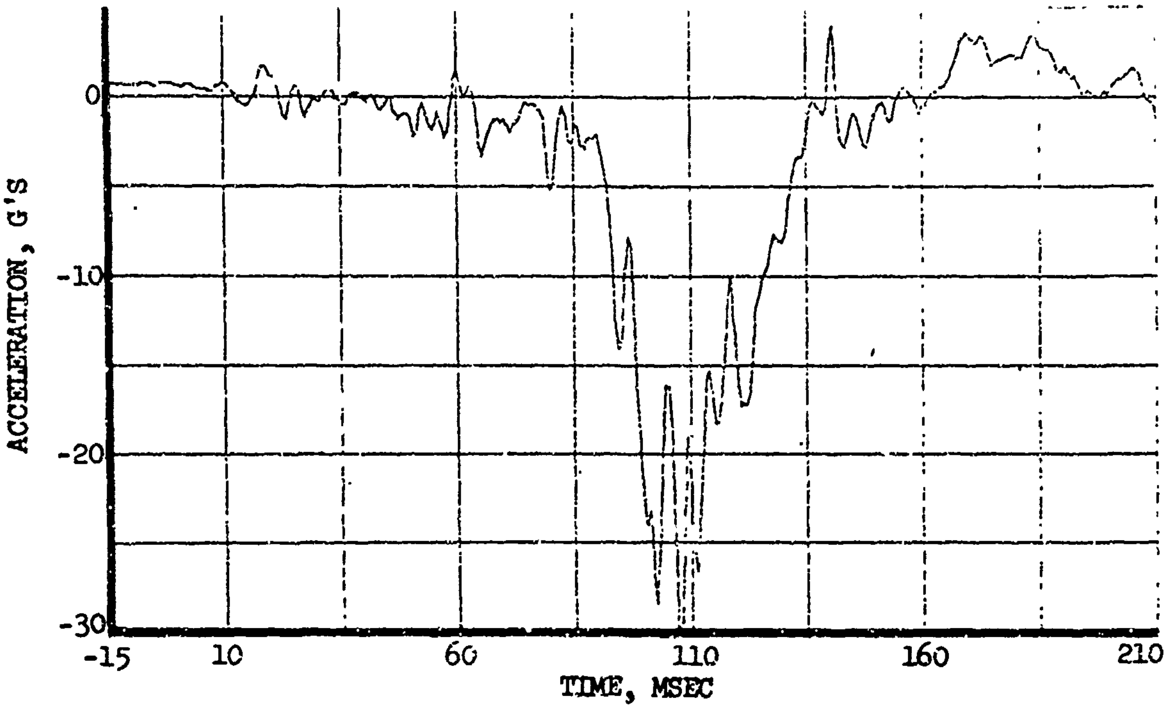


Figure 35. Recorded Time History, Transmission Rotor Housing, Vertical Acceleration (Channel 40).

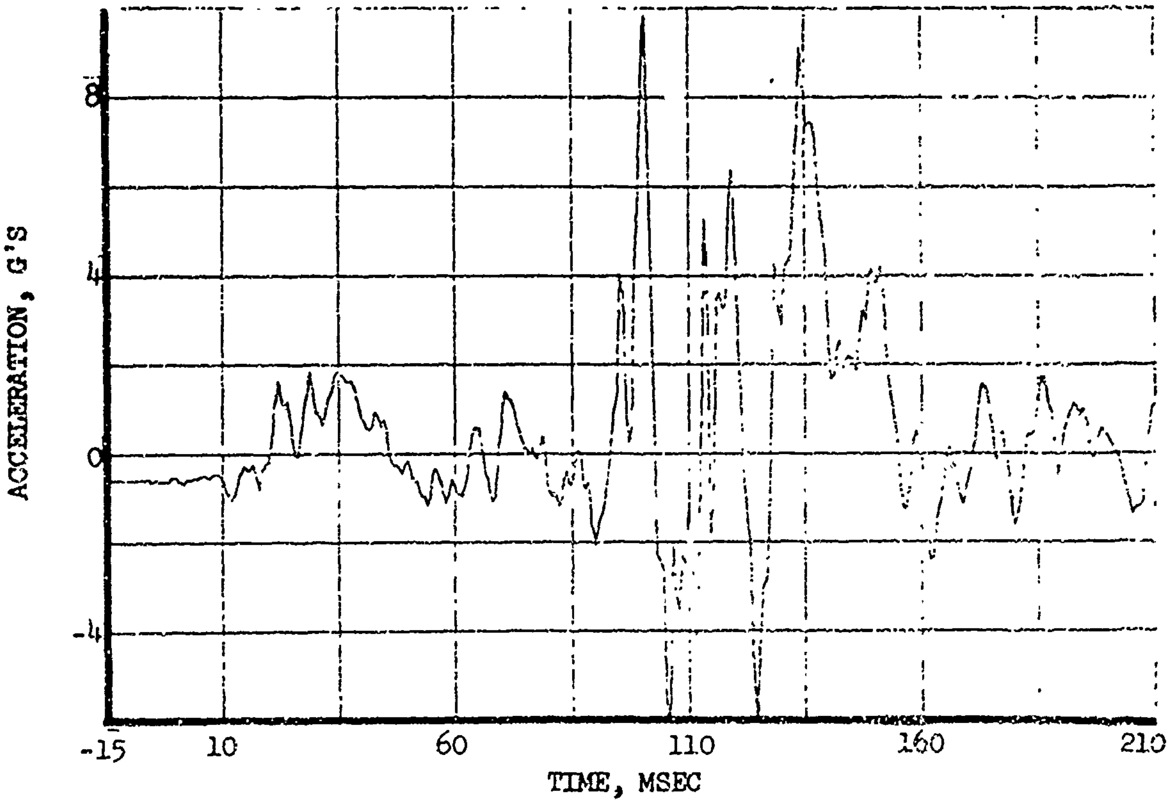


Figure 36. Recorded Time History, Transmission Rotor Housing, Lateral Acceleration (Channel 41).

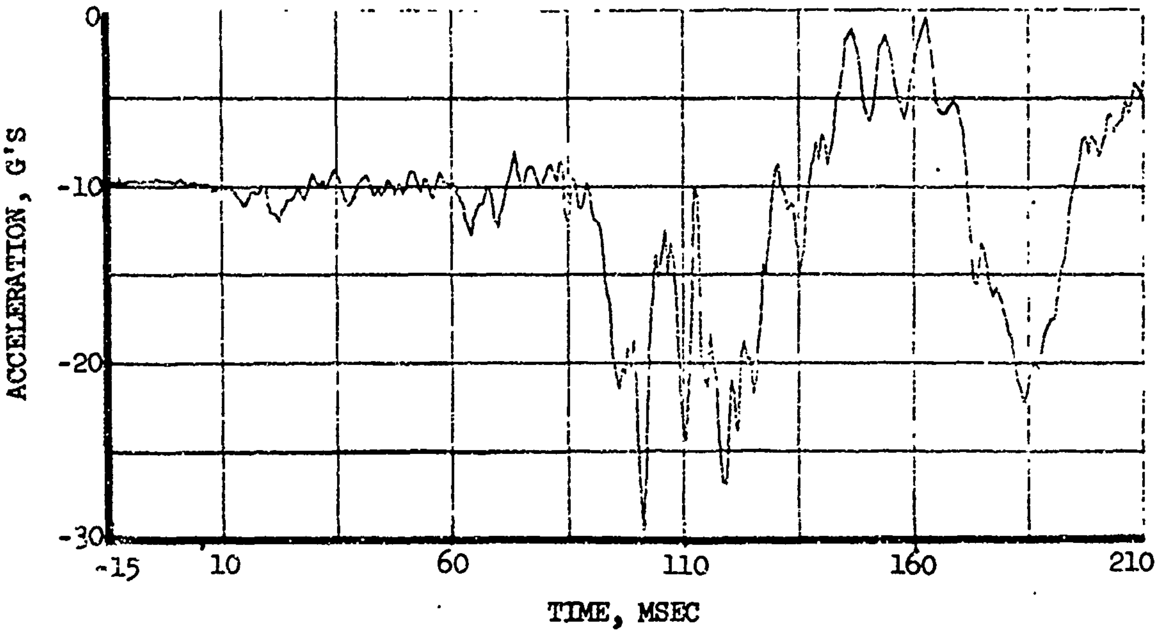


Figure 37. Recorded Time History, Transmission Rotor Housing, Axial Acceleration (Channel 42).

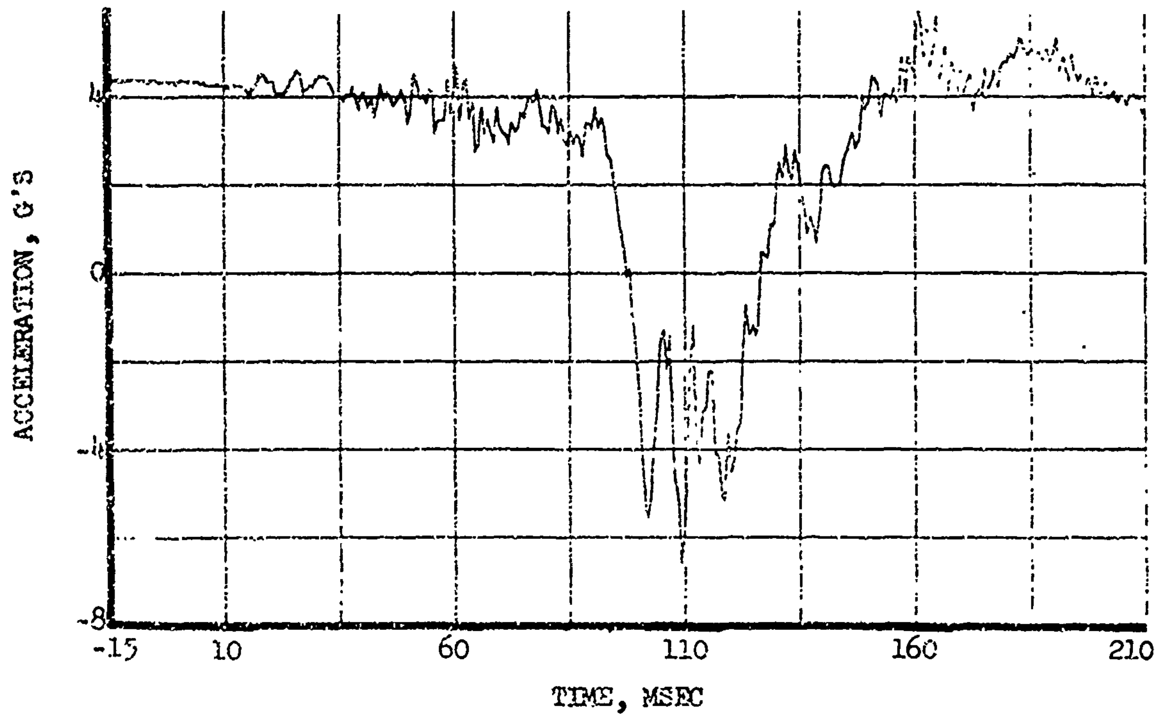


Figure 38. Recorded Time History, Engine, Vertical Acceleration (Channel 43).

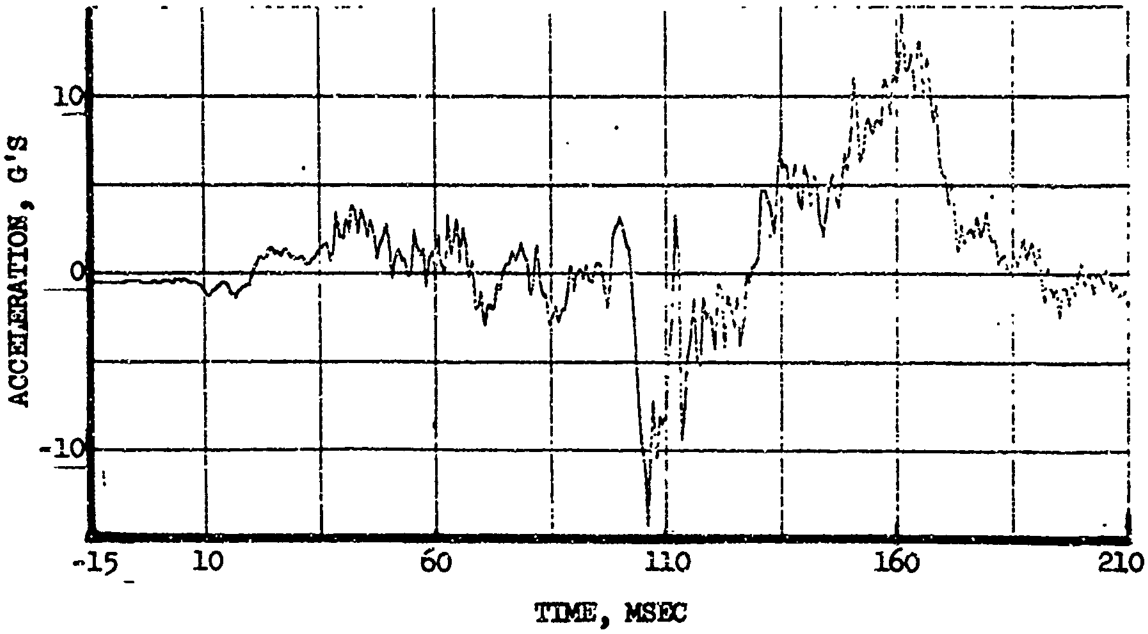


Figure 39. Recorded Time History, Engine, Lateral Acceleration (Channel 44).

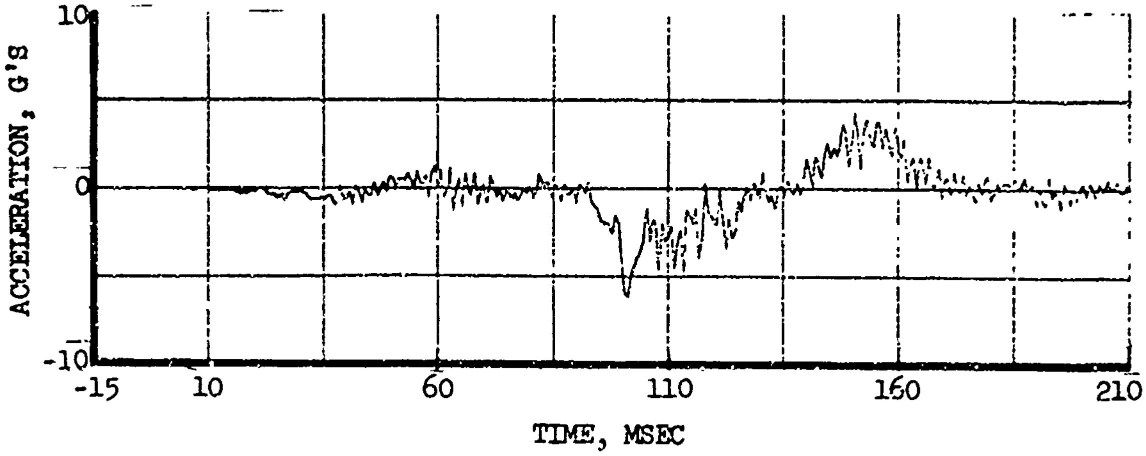


Figure 40. Recorded Time History, Engine, Axial Acceleration (Channel 45).

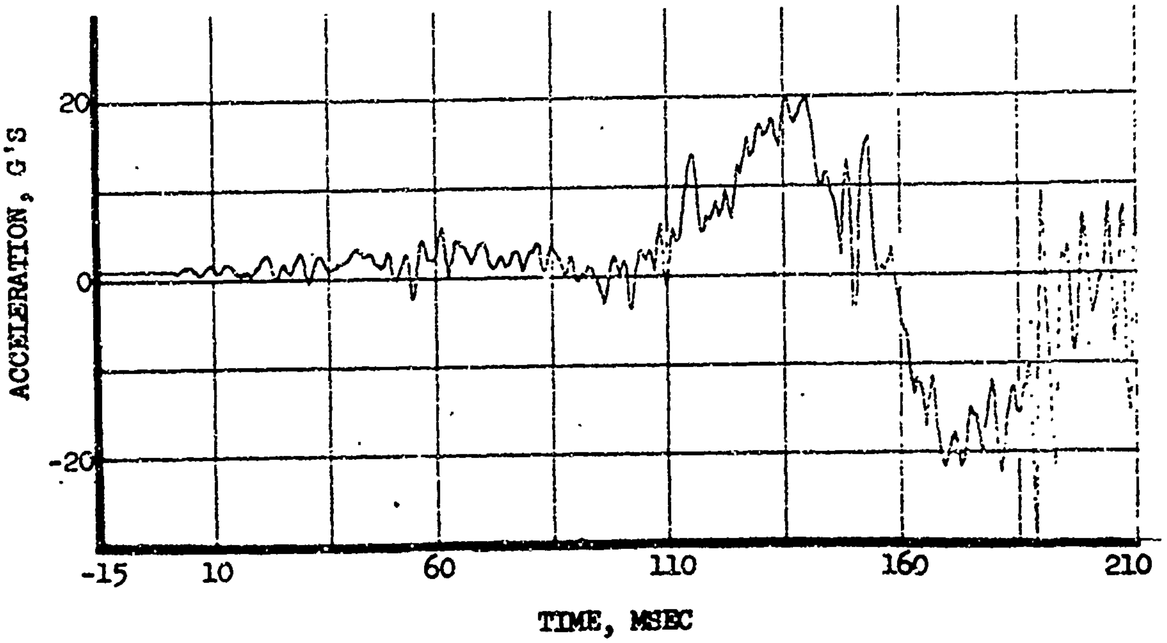


Figure 41. Recorded Time History, Tail Rotor Gearbox, Vertical Acceleration (Channel 46).

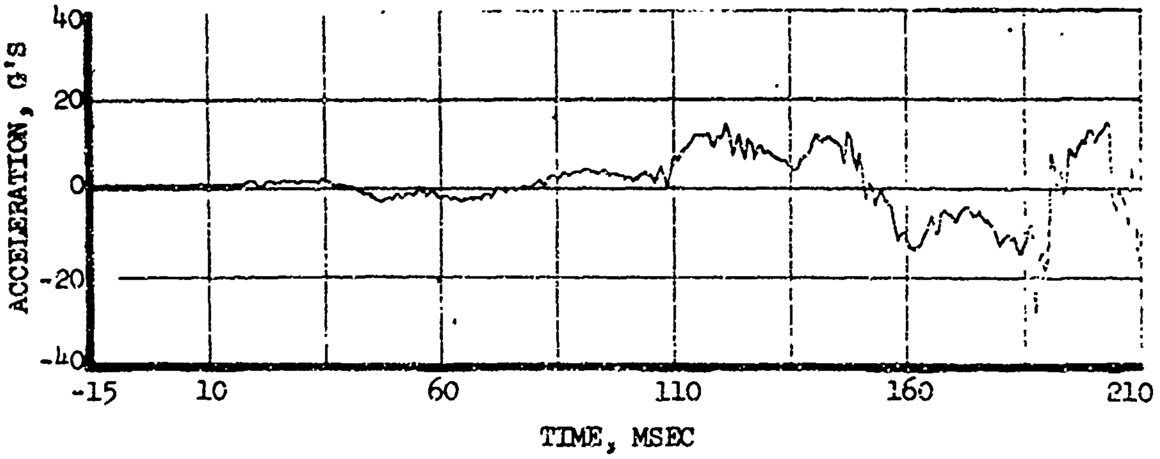


Figure 42. Recorded Time History, Tail Rotor Gearbox, Lateral Acceleration (Channel 47).

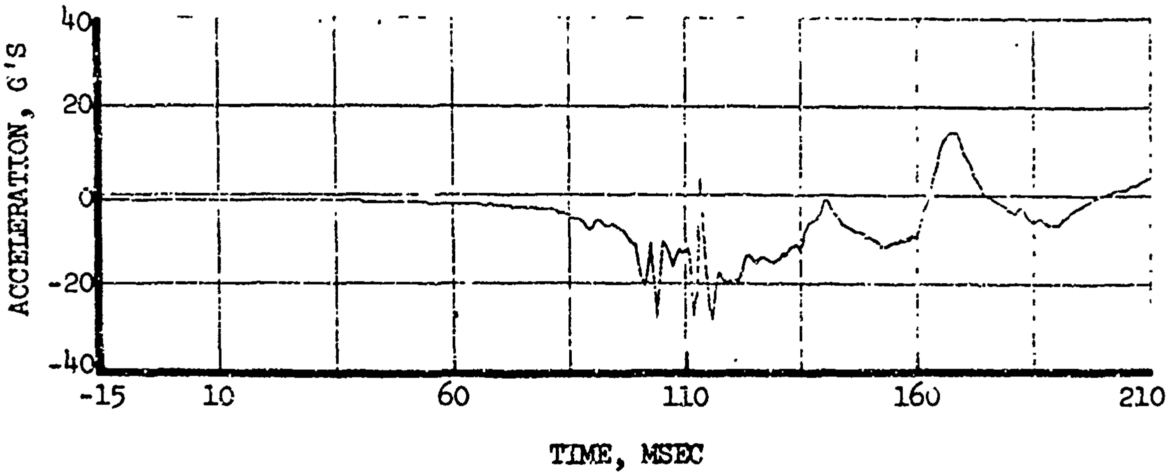


Figure 43. Recorded Time History, Passenger Pelvic, Vertical Acceleration (Channel 48).

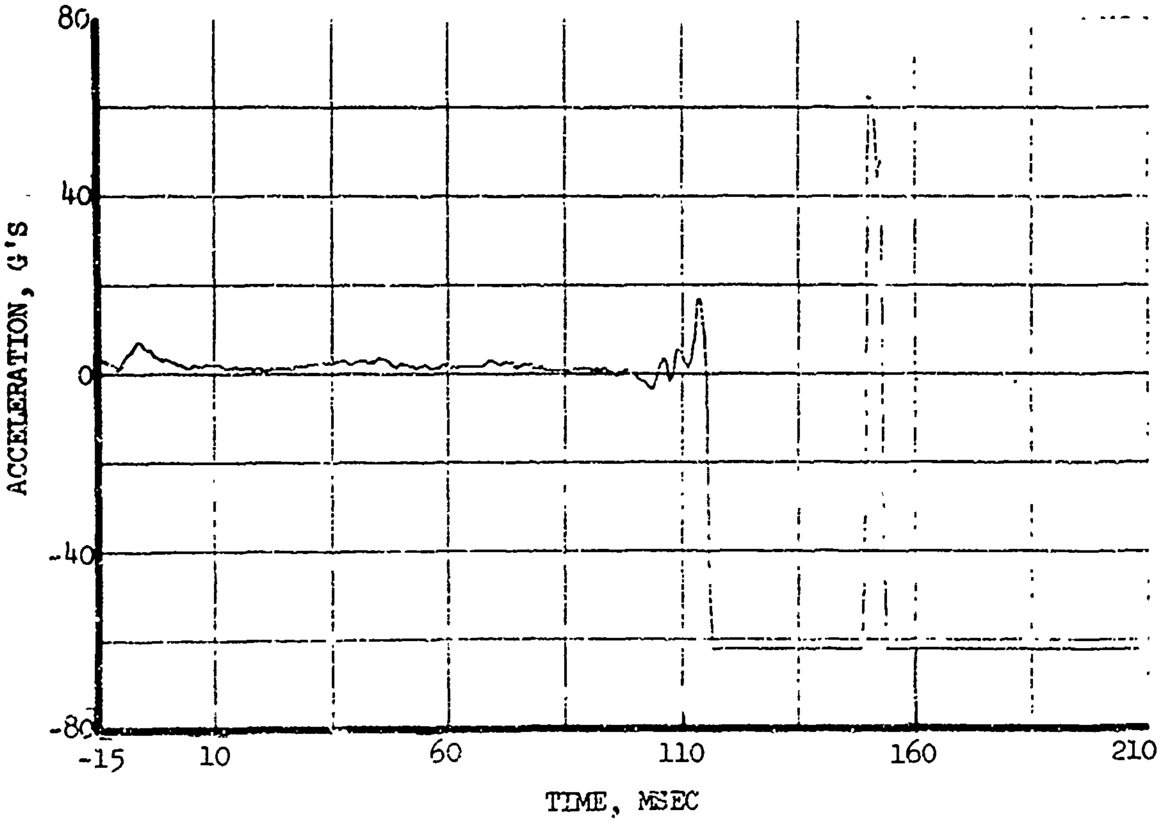


Figure 44. Recorded Time History, Passenger Pelvic, Lateral Acceleration (Channel 60).

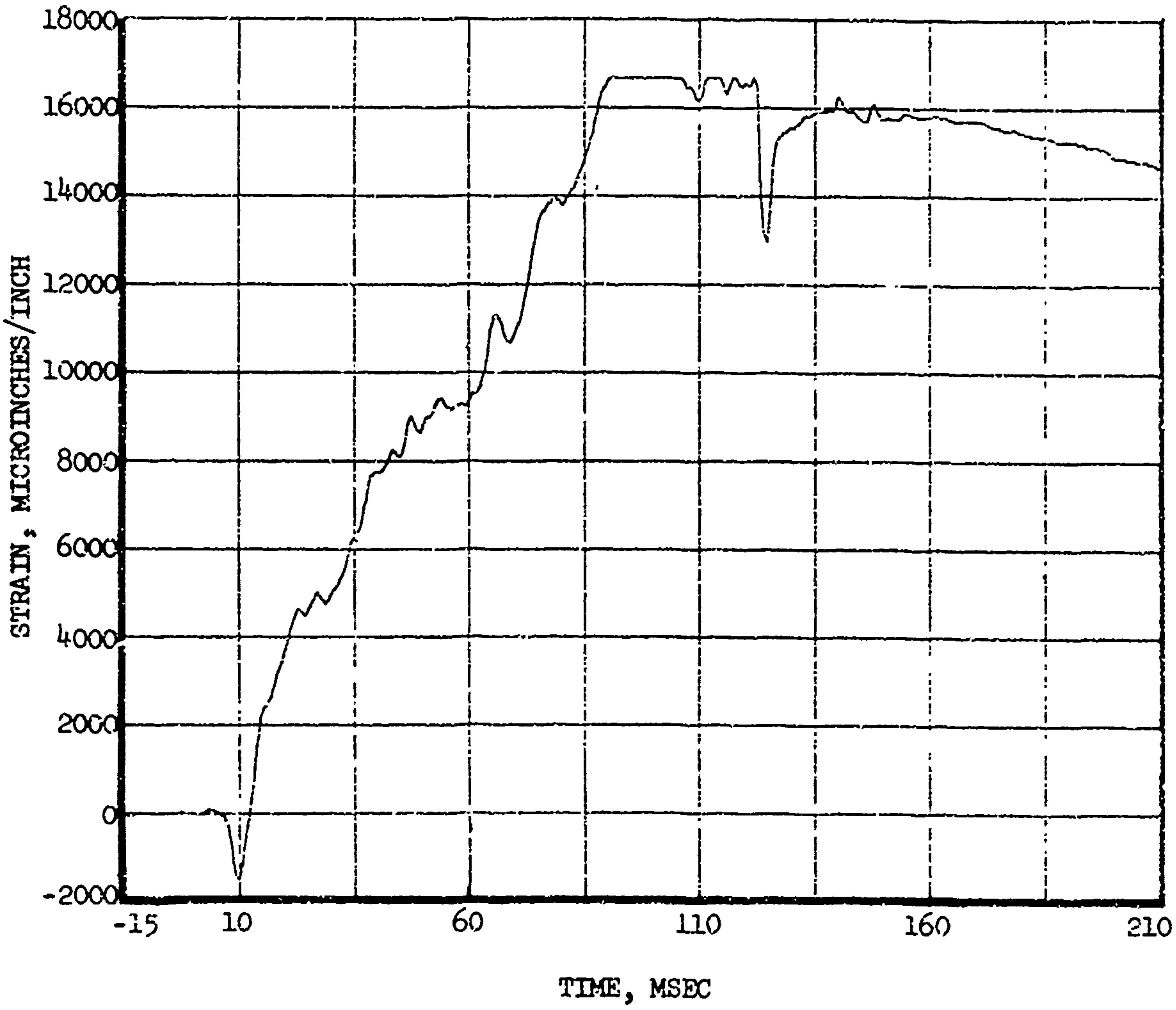


Figure 45. Recorded Time History, Forward Strut, Left Side Strain Gage (Channel 61).

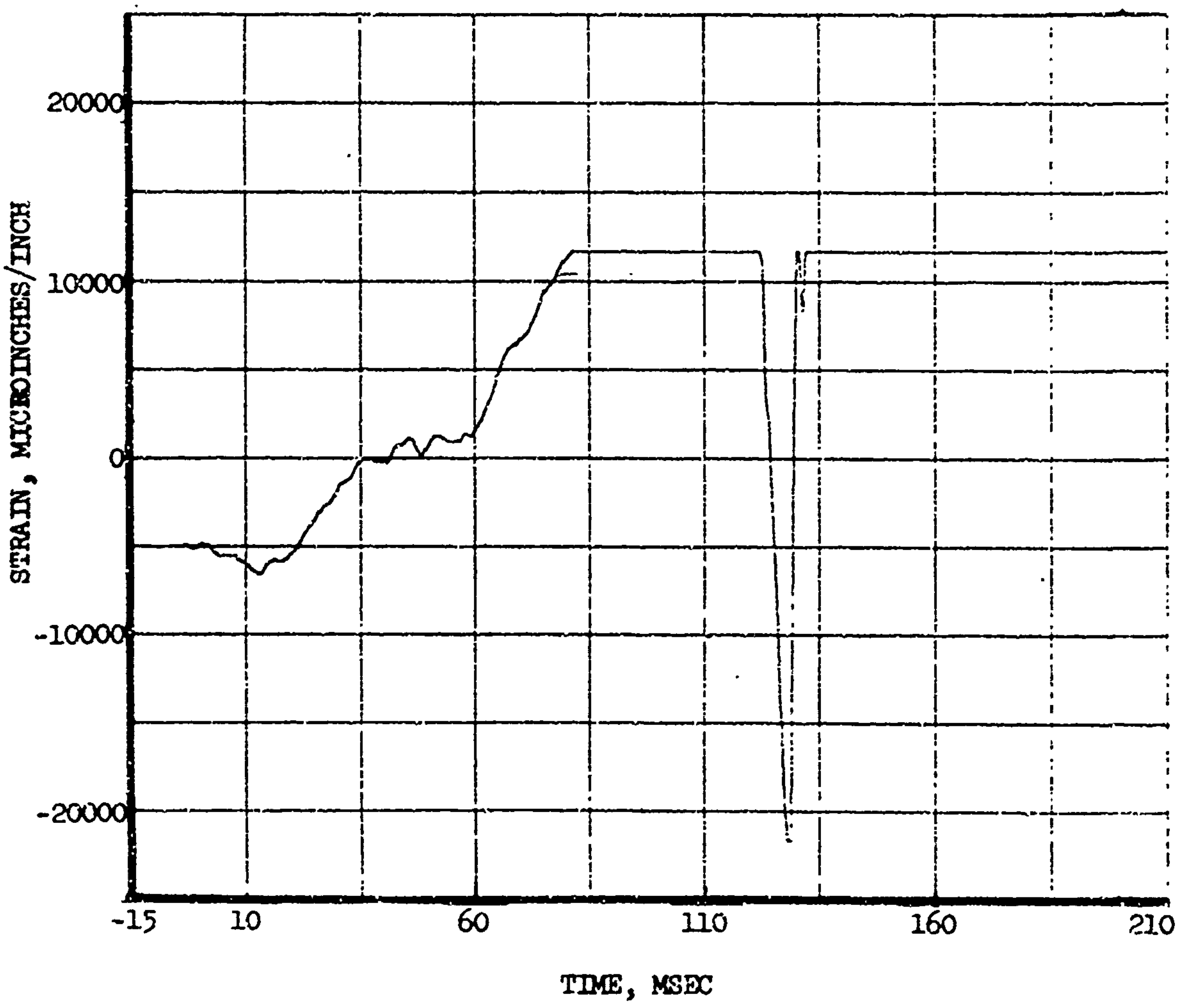


Figure 46. Recorded Time History, Rear Strut, Left Side, Strain Gage (Channel 62).

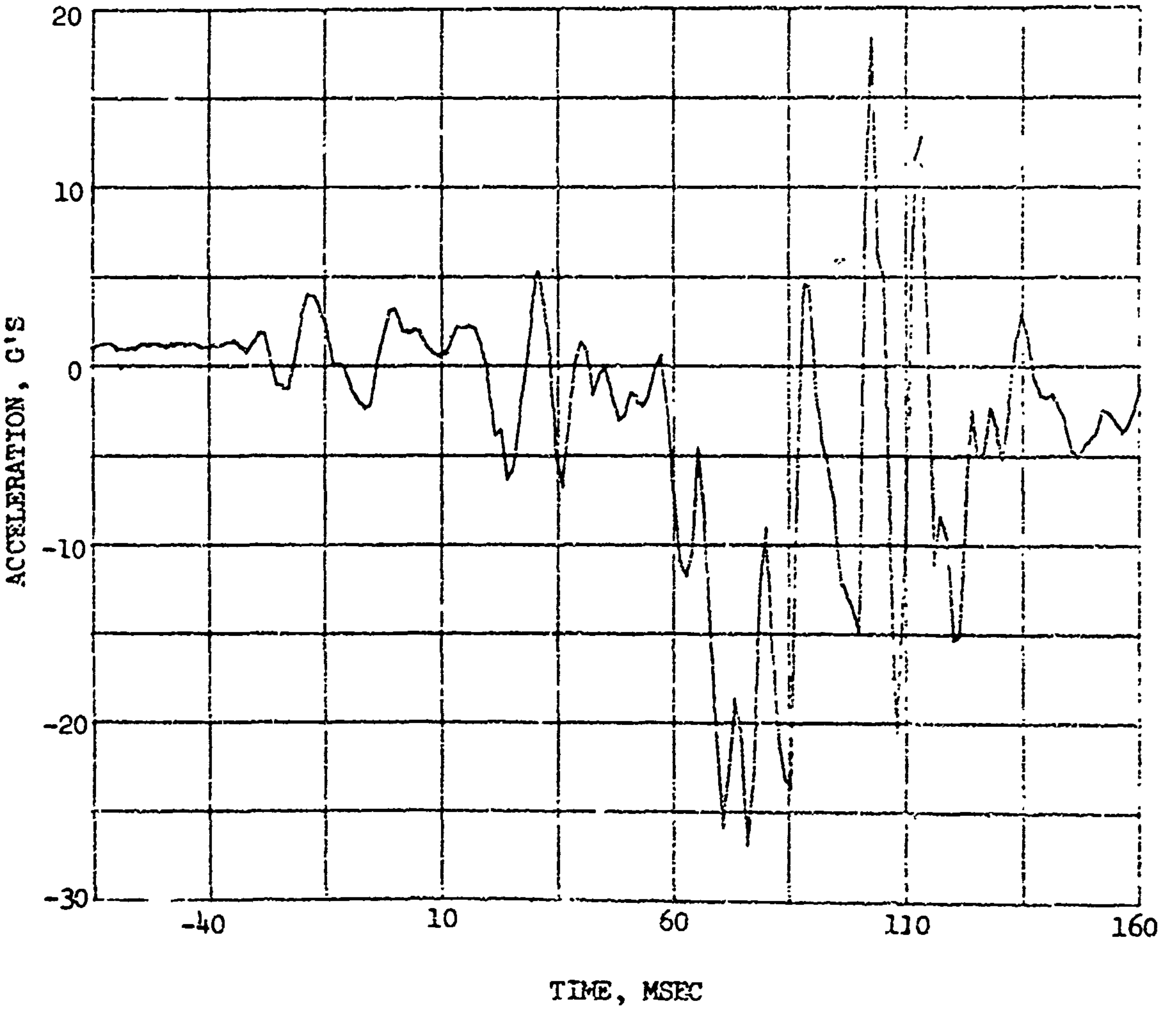


Figure 47. 100-CPS Low-Pass Filtered Test Data, Pilot Seat Pan, Vertical Acceleration (Channel 07).

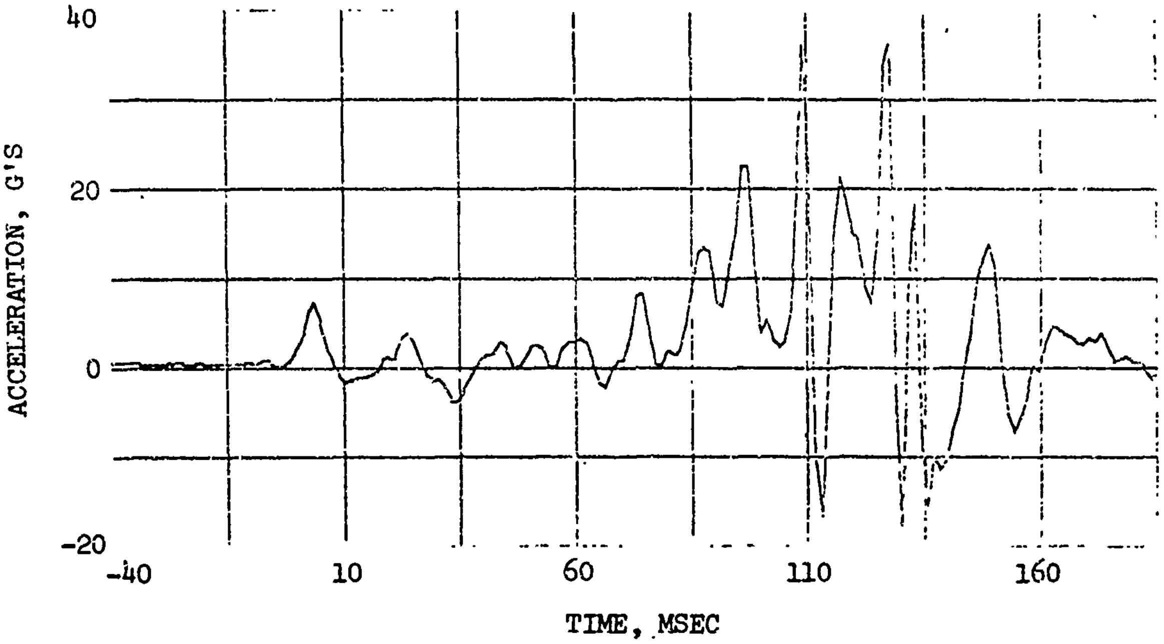


Figure 48. 100-CPS Low-Pass Filtered Test Data, Pilot Seat Pan, Lateral Acceleration (Channel 08).

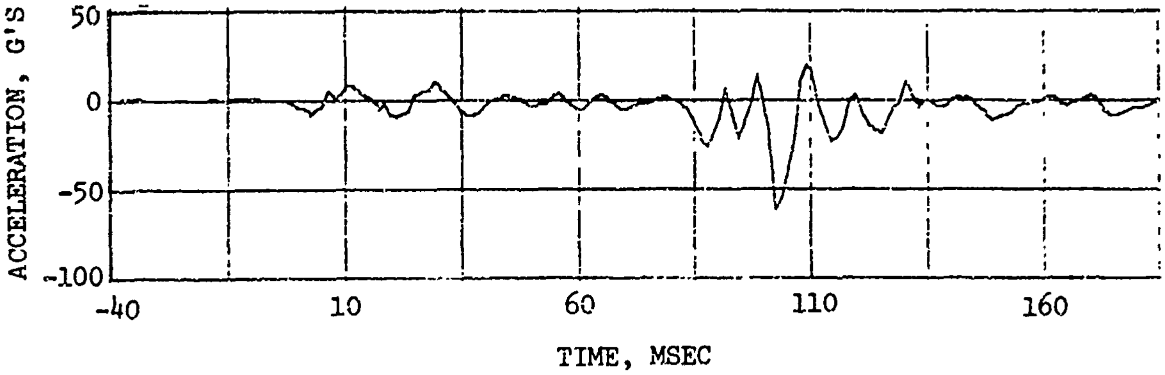


Figure 49. 100-CPS Low-Pass Filtered Test Data, Copilot Seat Pan Vertical Acceleration (Channel 09).

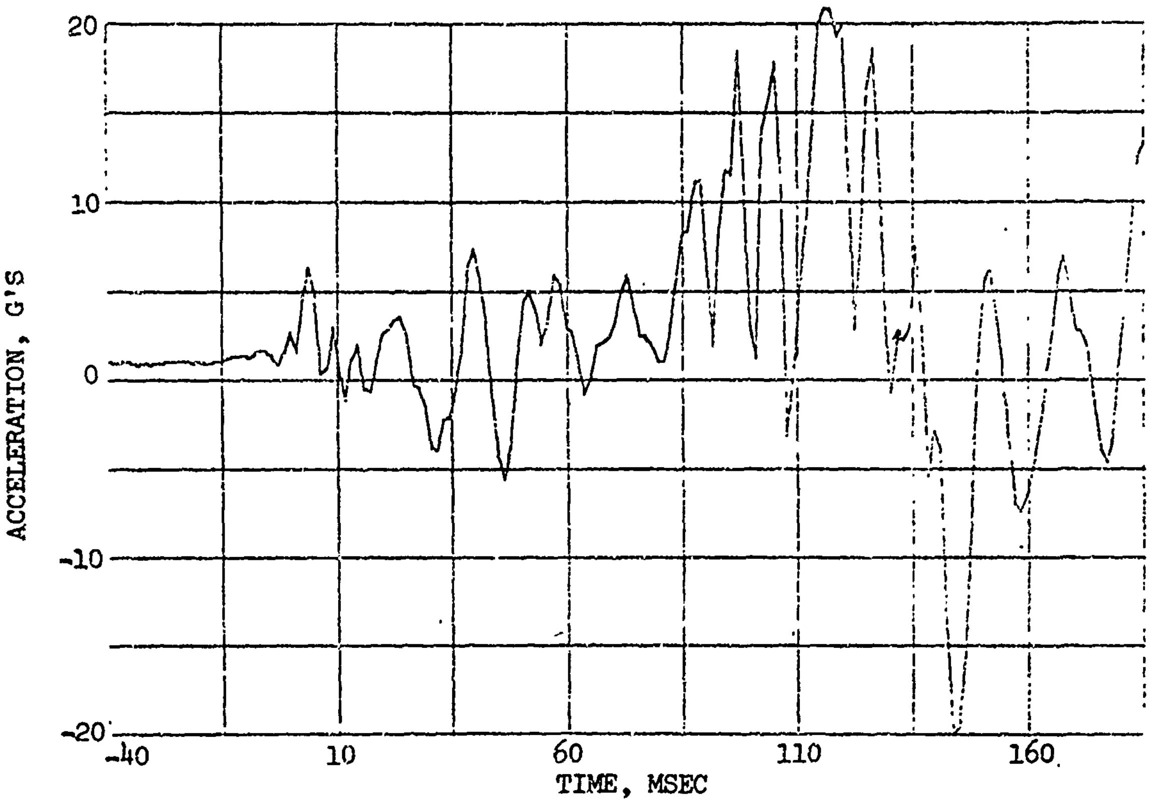


Figure 50. 100-CPS Low-Pass Filtered Test Data, Copilot Seat Pan, Lateral Acceleration (Channel 10).

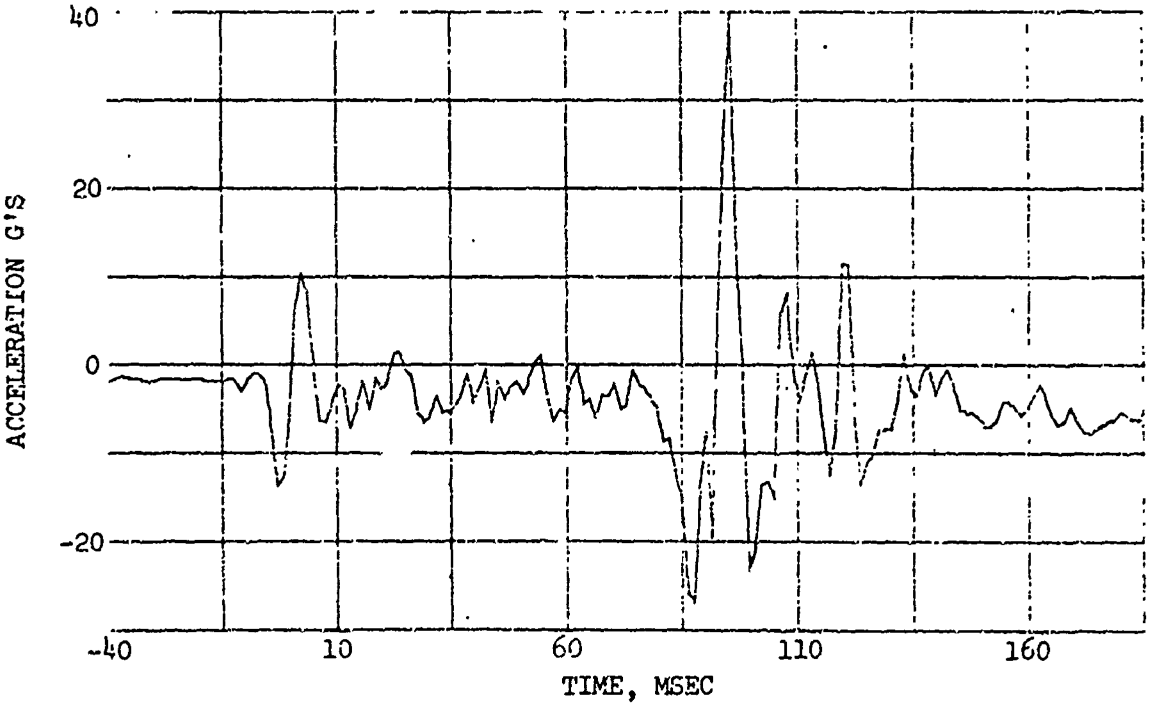


Figure 51. 100-CPS Low-Pass Filtered Test Data, Copilot Floor, Vertical Acceleration (Channel 30).

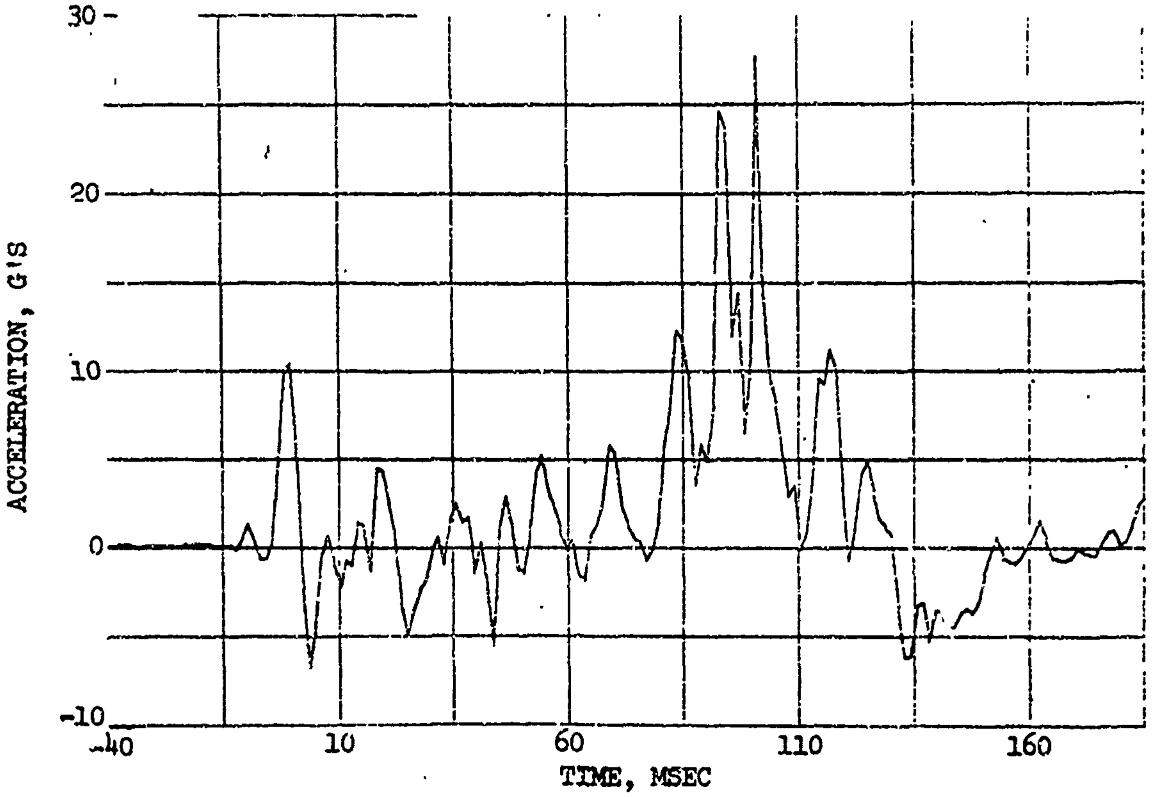


Figure 52. 100-CPS Low-Pass Filtered Test Data, Copilot Floor, Lateral Acceleration (Channel 31).

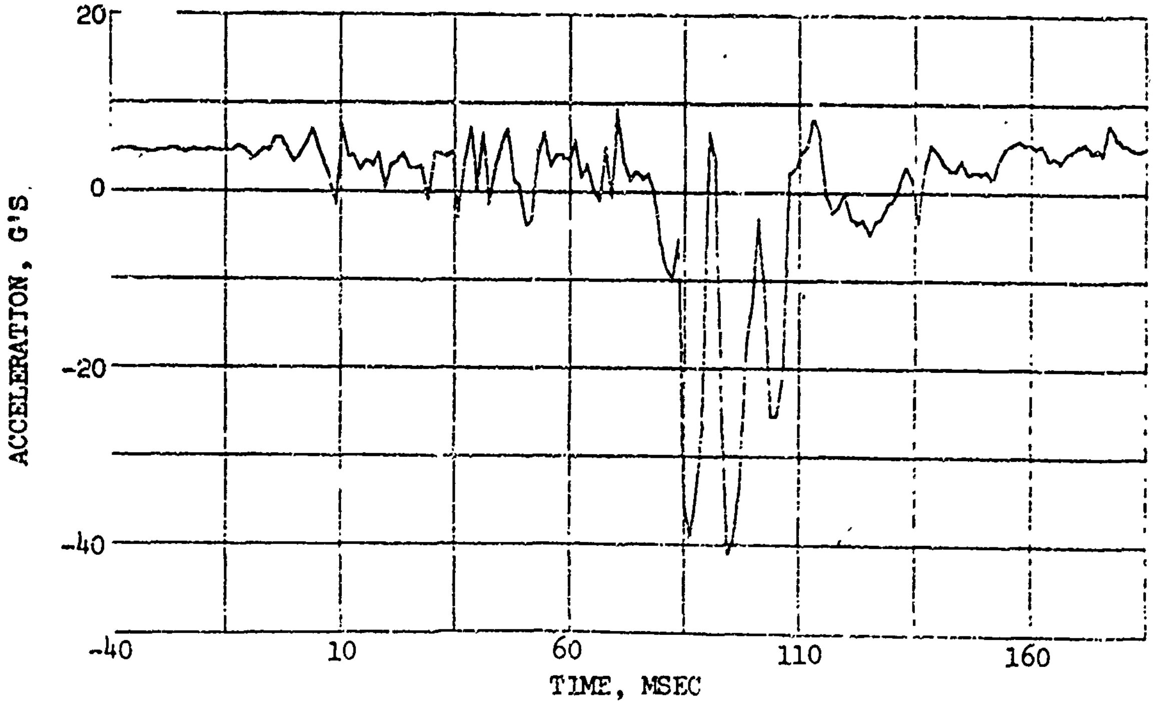


Figure 53. 100-CPS Low-Pass Filtered Test Data, Passenger Floor, Vertical Acceleration (Channel 36).

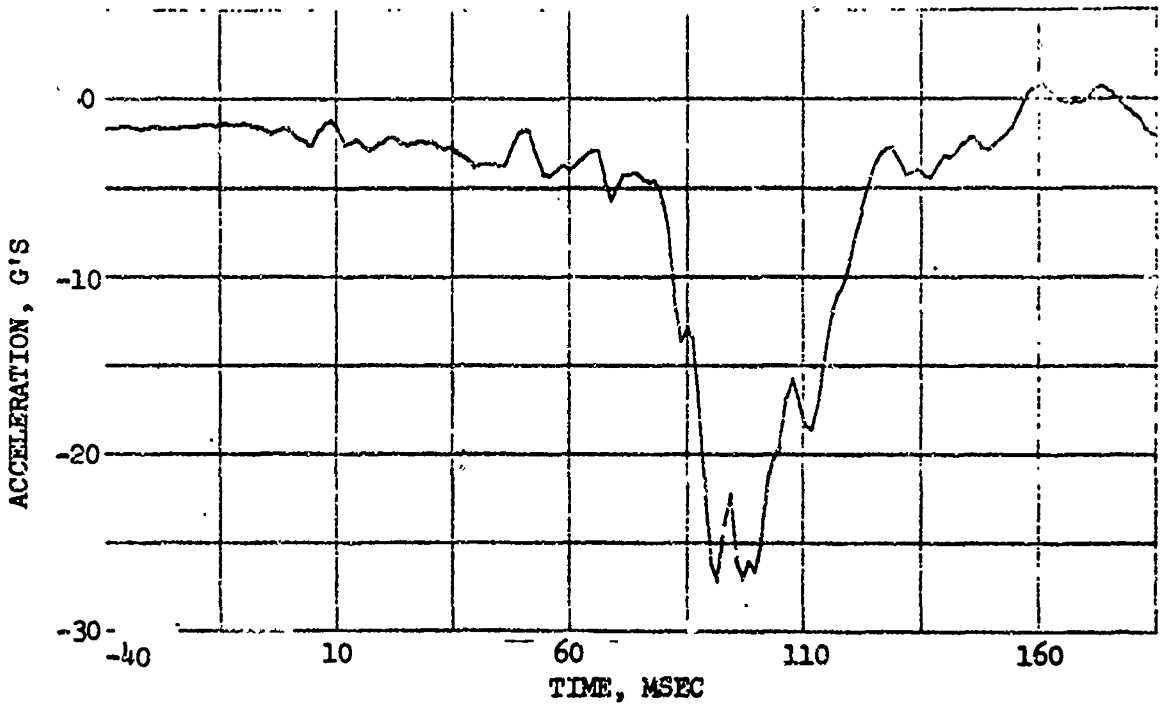


Figure 54. 100-CPS Low-Pass Filtered Test Data, Transmission Rotor Housing, Vertical Acceleration (Channel 40).

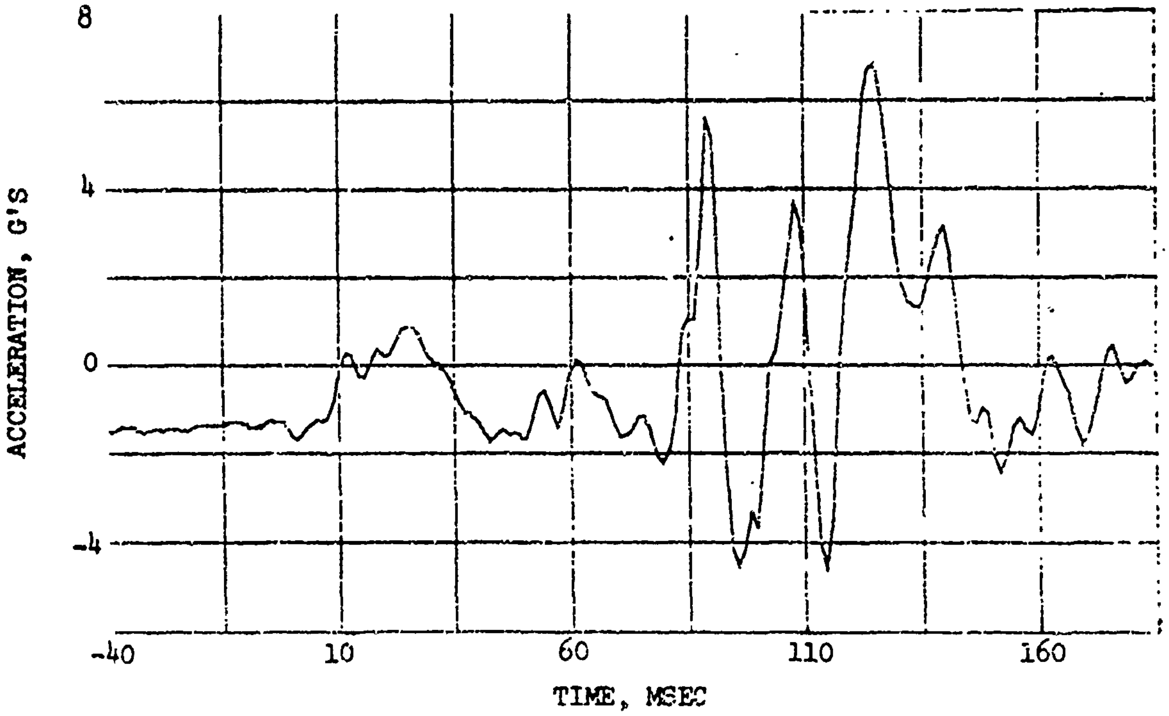


Figure 55. 100-CPS Low-Pass Filtered Test Data, Transmission Rotor Housing, Lateral Acceleration (Channel 41).

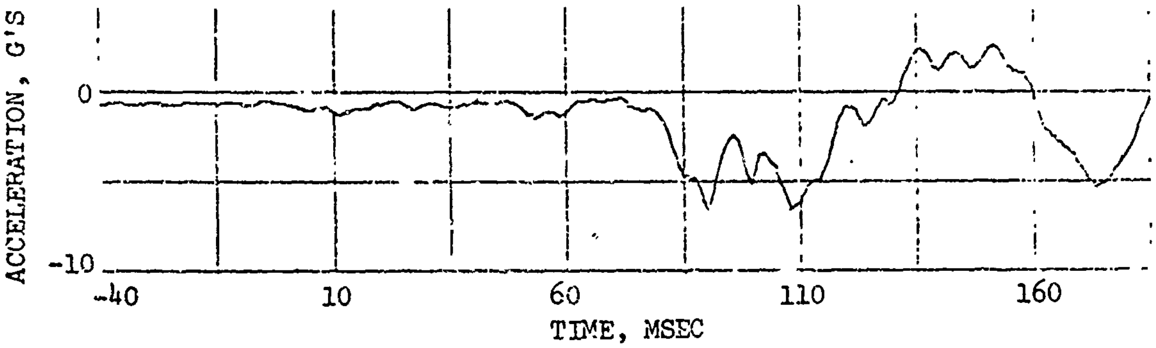


Figure 56. 100-CPS Low-Pass Filtered Test Data, Transmission Rotor Housing, Axial Acceleration (Channel 42).

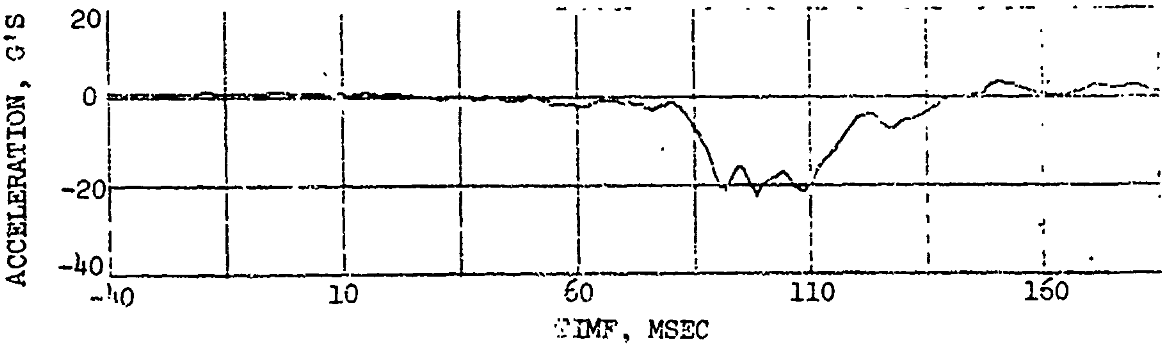


Figure 57. 100-CPS Low-Pass Filtered Test Data, Engine, Vertical Acceleration (Channel 43).

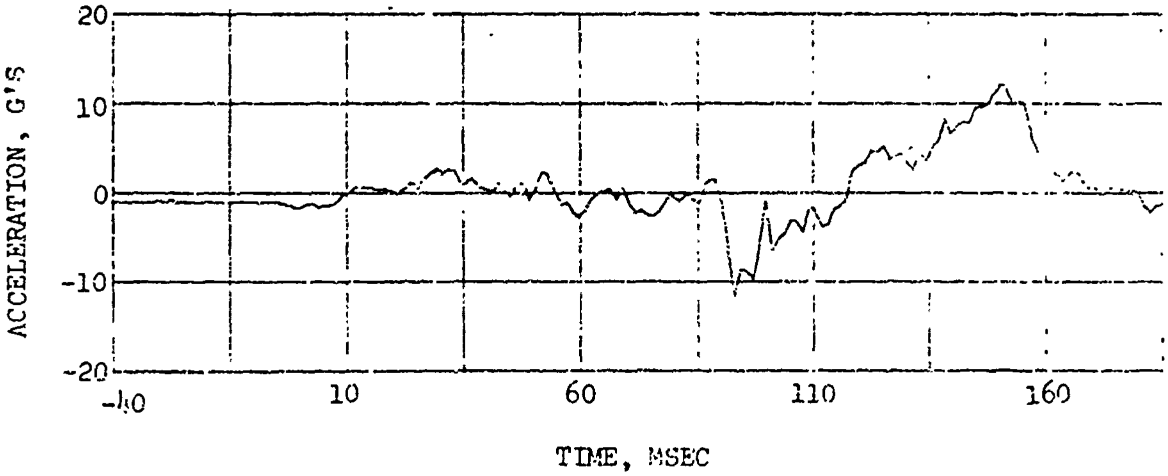


Figure 58. 100-CPS Low-Pass Filtered Test Data, Engine, Lateral Acceleration (Channel 44).

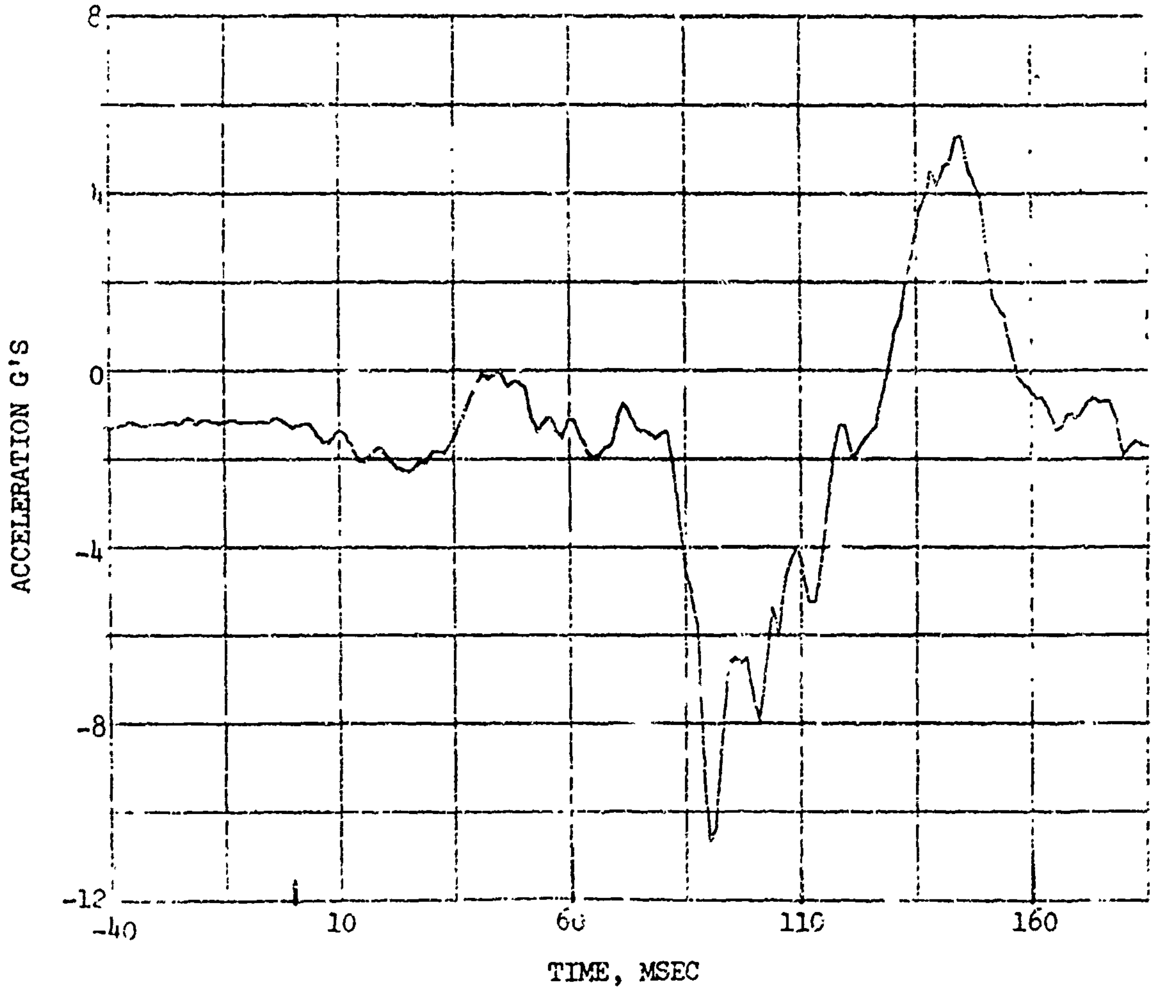


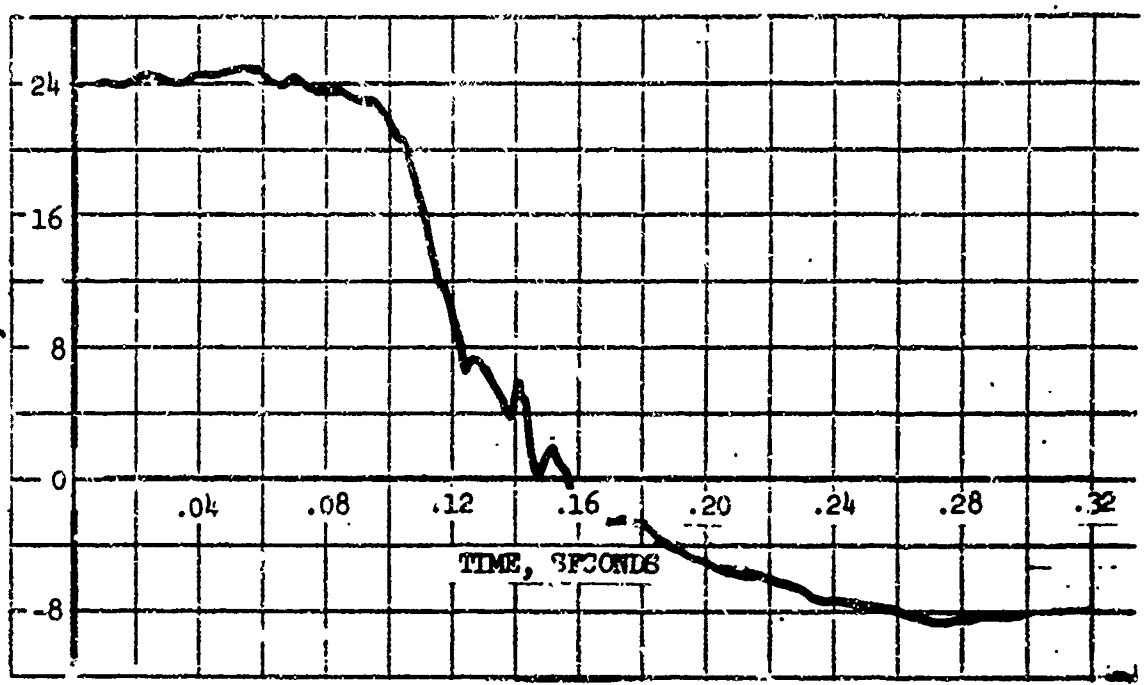
Figure 59. 100-CPS Low-Pass Filtered Test Data, Engine, Axial Acceleration (Channel 45).

TIME HISTORIES OF INTEGRATED DATA

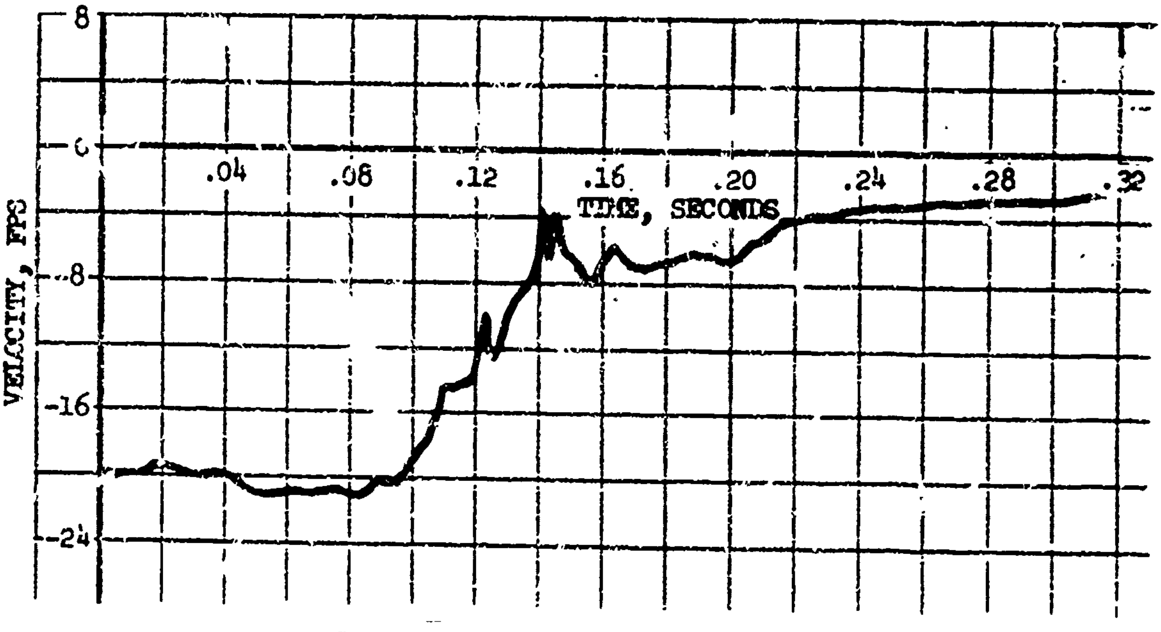
The integrated velocities and displacements were obtained from the recorded accelerations. A digital program was written which numerically integrated the acceleration time histories using a trapezoidal rule and an integration time interval of .0008. The acceleration data was adjusted to account for channel noise, offset accelerations due to initial swing positions, and post-test position changes resulting from one or more of the following sources: structural damage, seat collapse, floor buckling, and passenger movement. The velocities obtained from integrating the accelerations are shown in Figures 60 through 70. The displacements obtained from the integrated velocities are shown in Figures 71 through 82.

IMPACT VELOCITY DATA

Figures 83 through 87 are obtained from analysis of the high speed film and show the sequence of events and the vertical and lateral velocities and displacements.

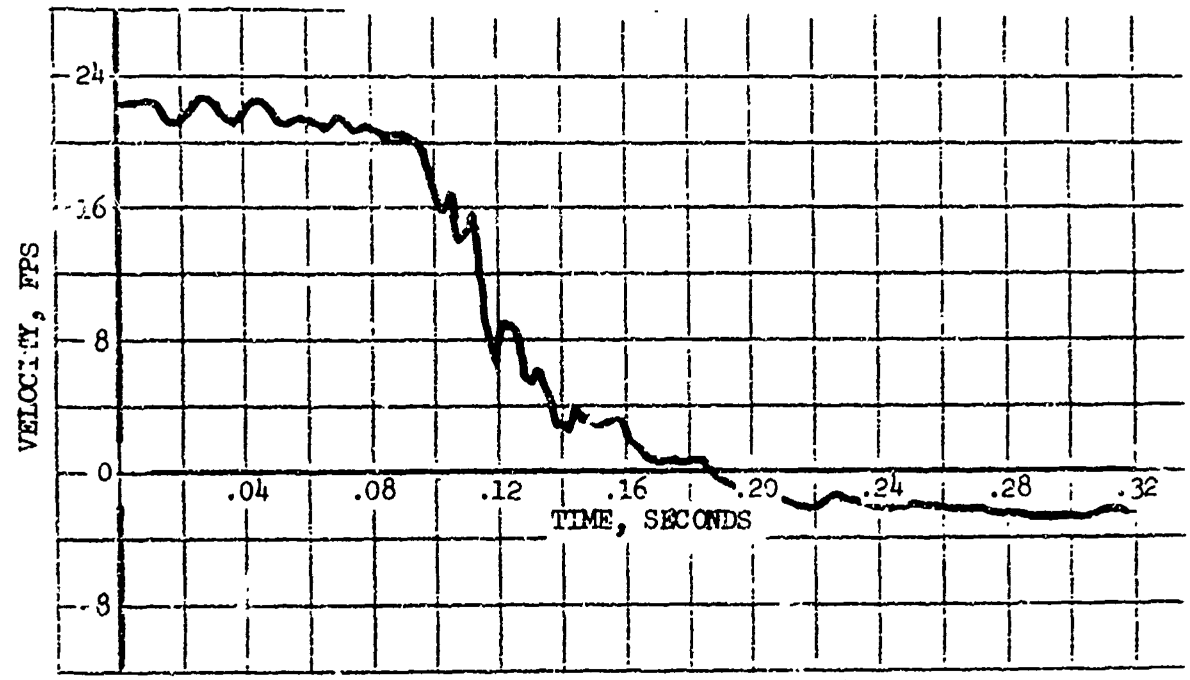


PILOT SEAT PAN, VERTICAL, CHANNEL 07

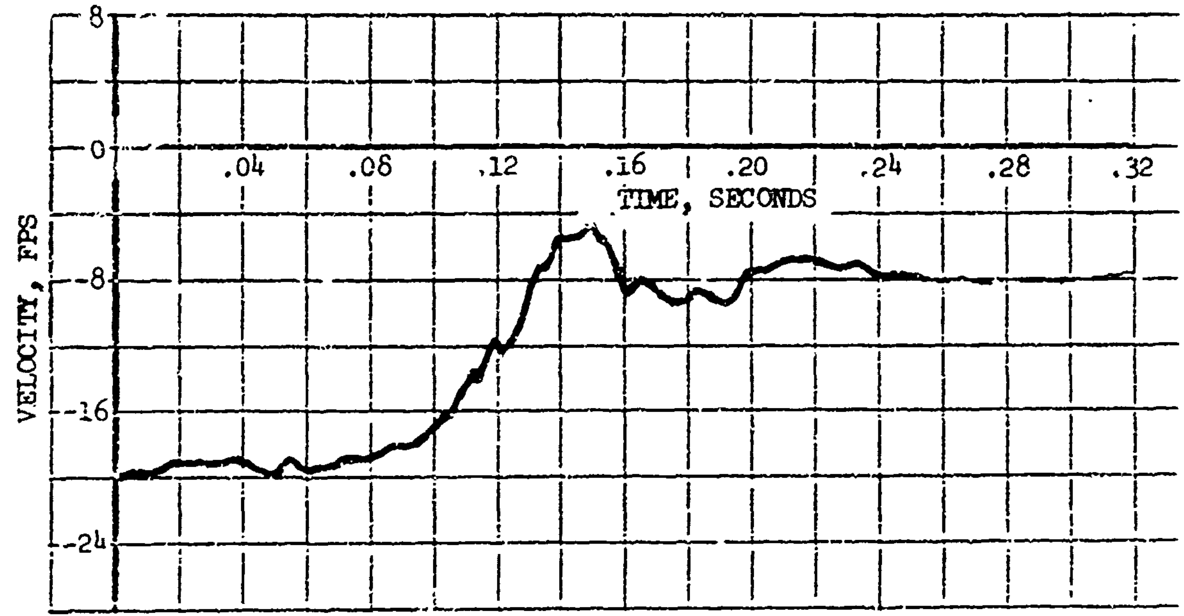


PILOT SEAT PAN, LATERAL, CHANNEL 08

Figure 60. Integrated Velocities, Pilot Seat Pan.

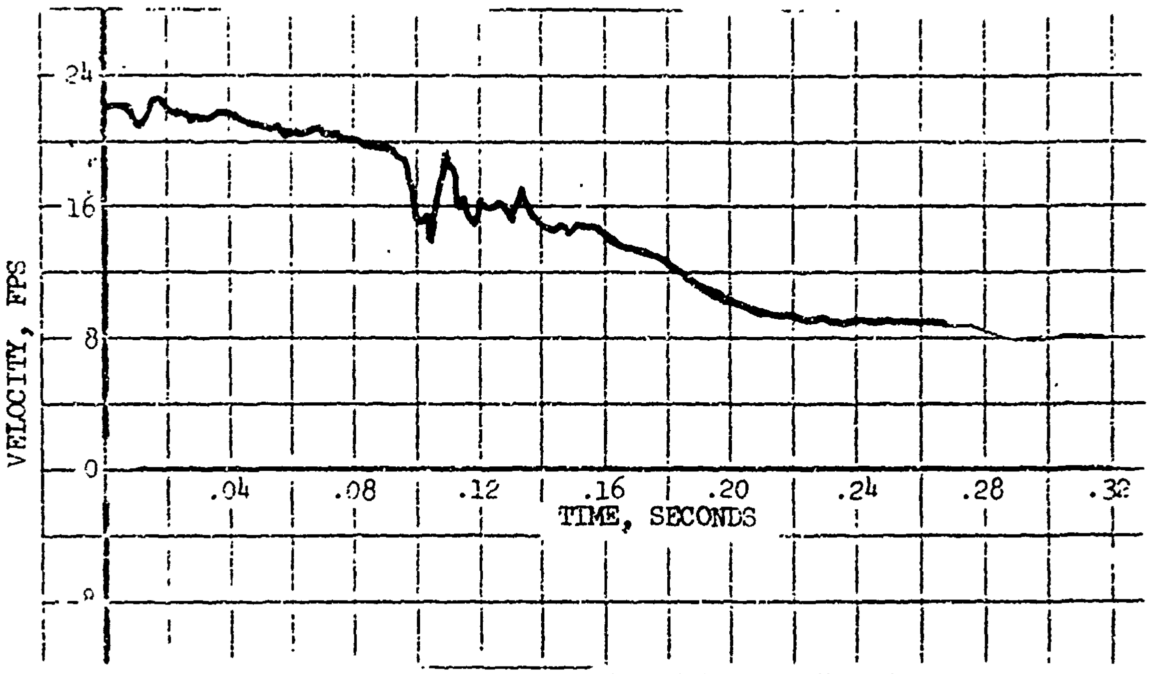


COPILOT SEAT PAN, VERTICAL, CHANNEL 09

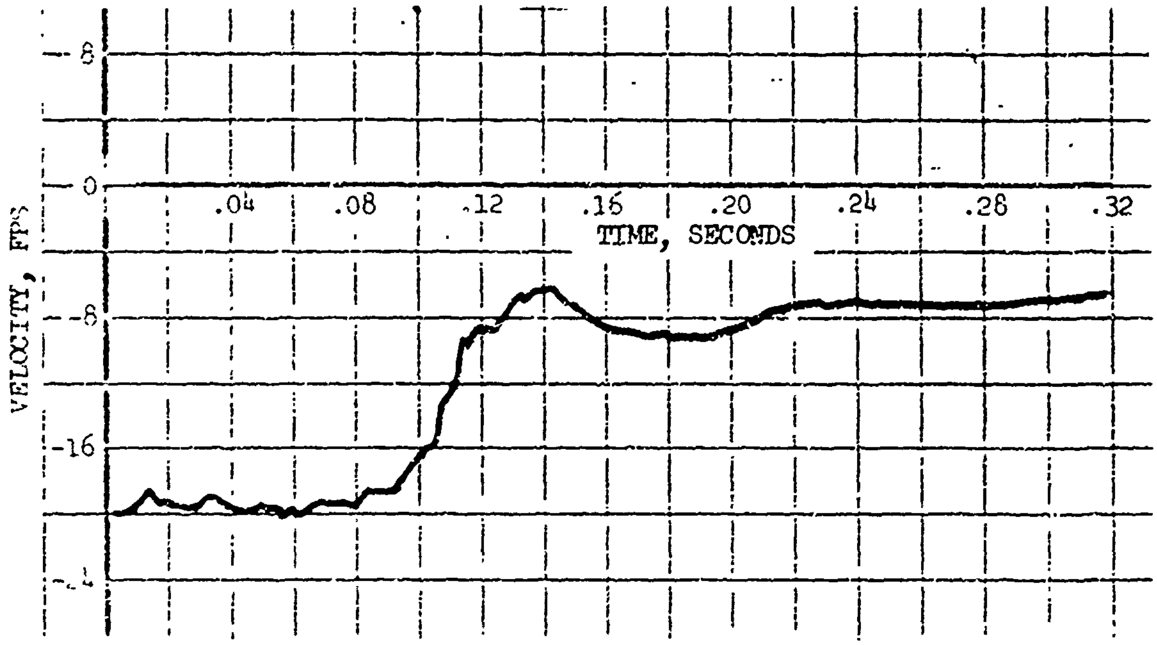


COPILOT SEAT PAN, LATERAL, CHANNEL 10

Figure 61. Integrated Velocities, Copilot Seat Pan.

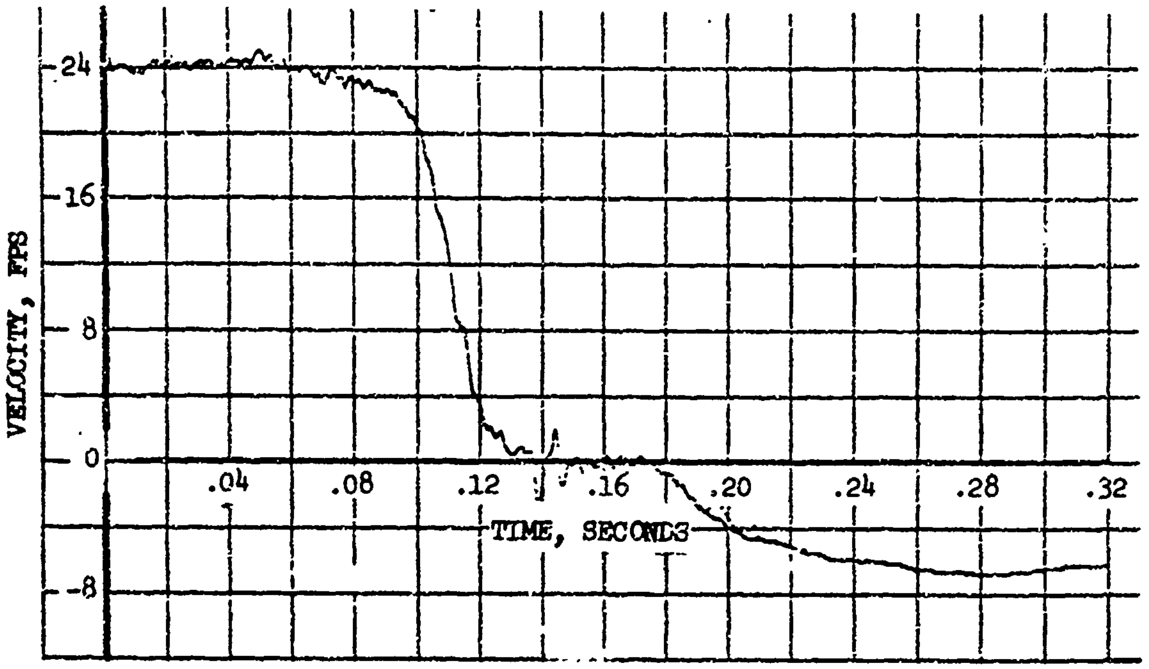


FLOOR, PILOT LOC., VERTICAL, CHANNEL 32

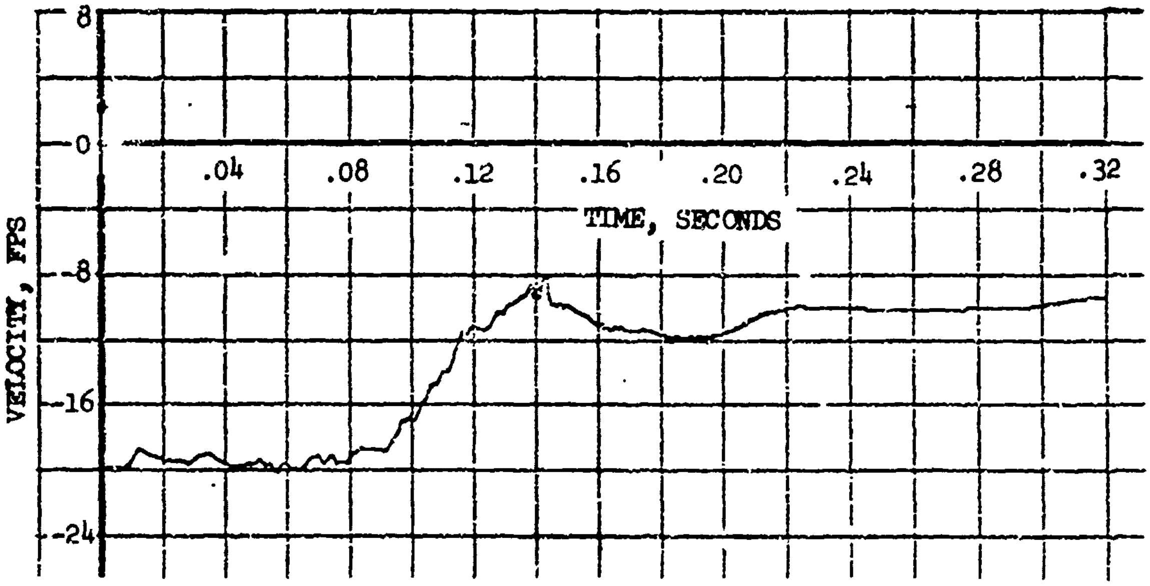


FLOOR, PILOT LOC., LATERAL, CHANNEL 33

Figure 6[illegible]. Integrated Velocities, Floor, Copilot Location

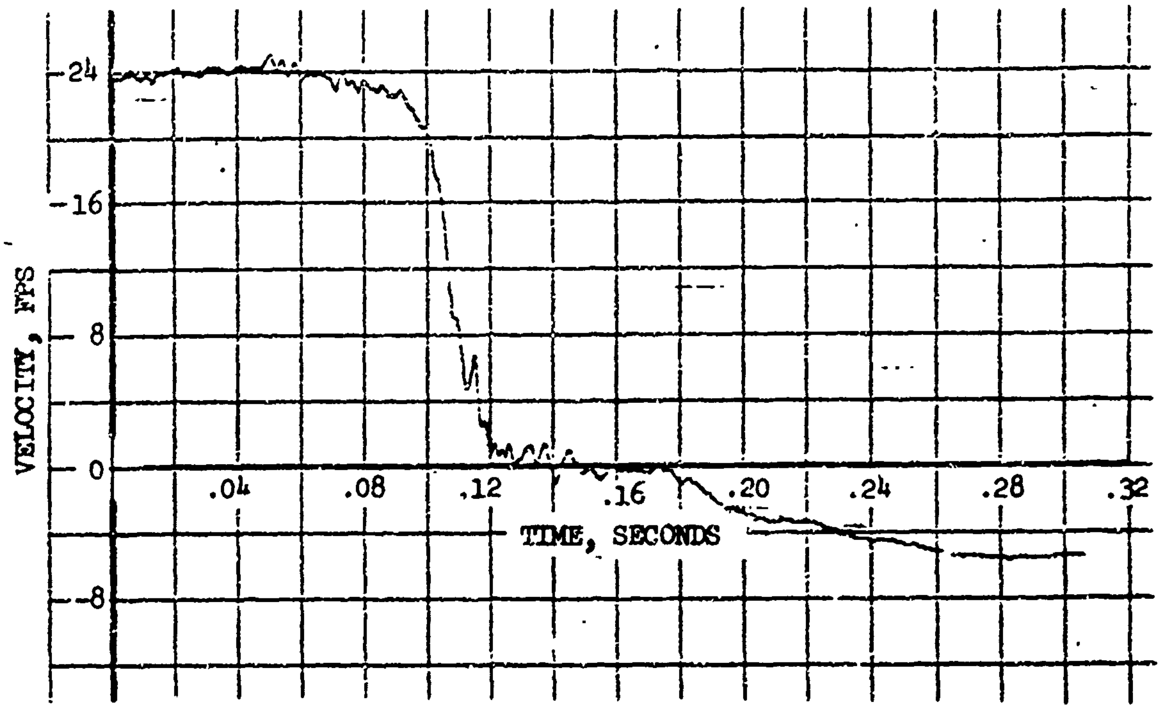


FLOOR, PILOT LOC., VERTICAL, CHANNEL 32

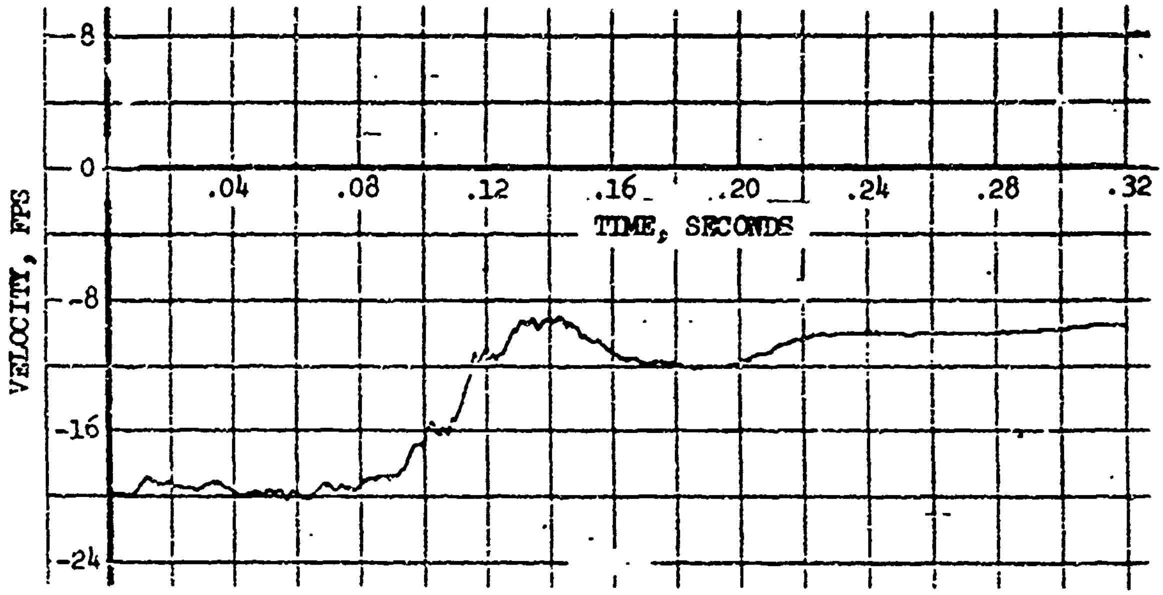


FLOOR, PILOT LOC., LATERAL, CHANNEL 33

Figure 63. Integrated Velocities, Floor, Pilot Location

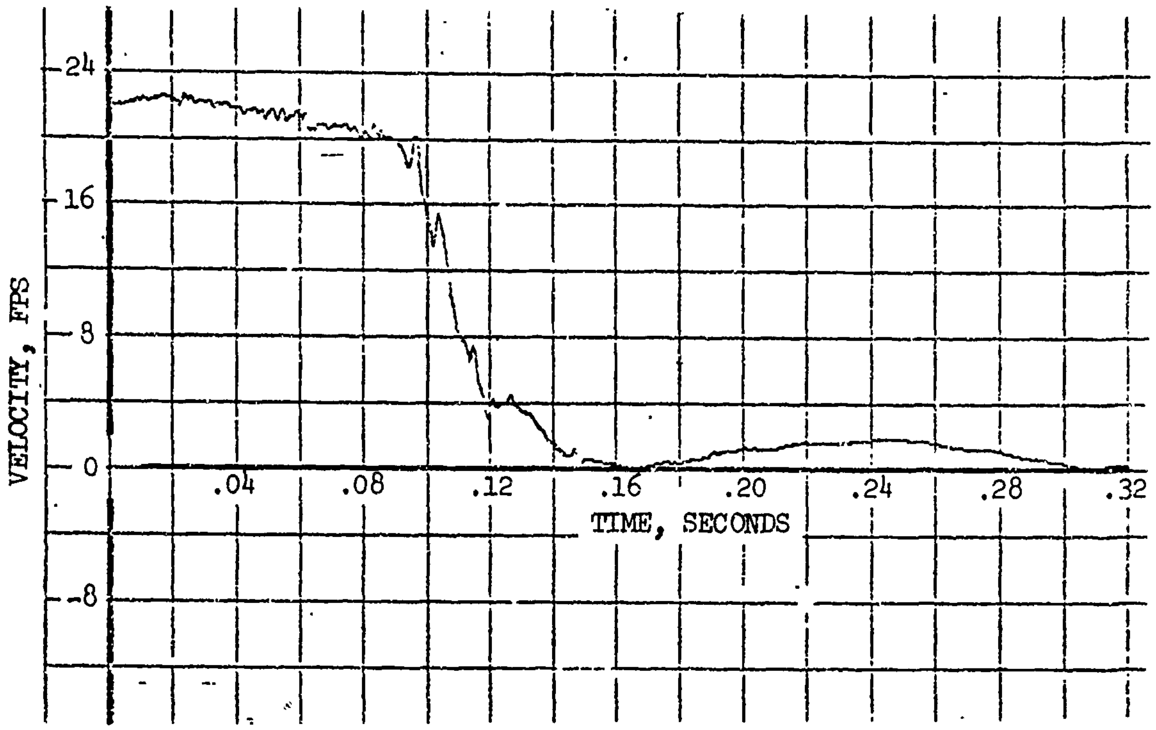


CARGO FLOOR, FWD. RIGHT, VERTICAL, CHANNEL 34

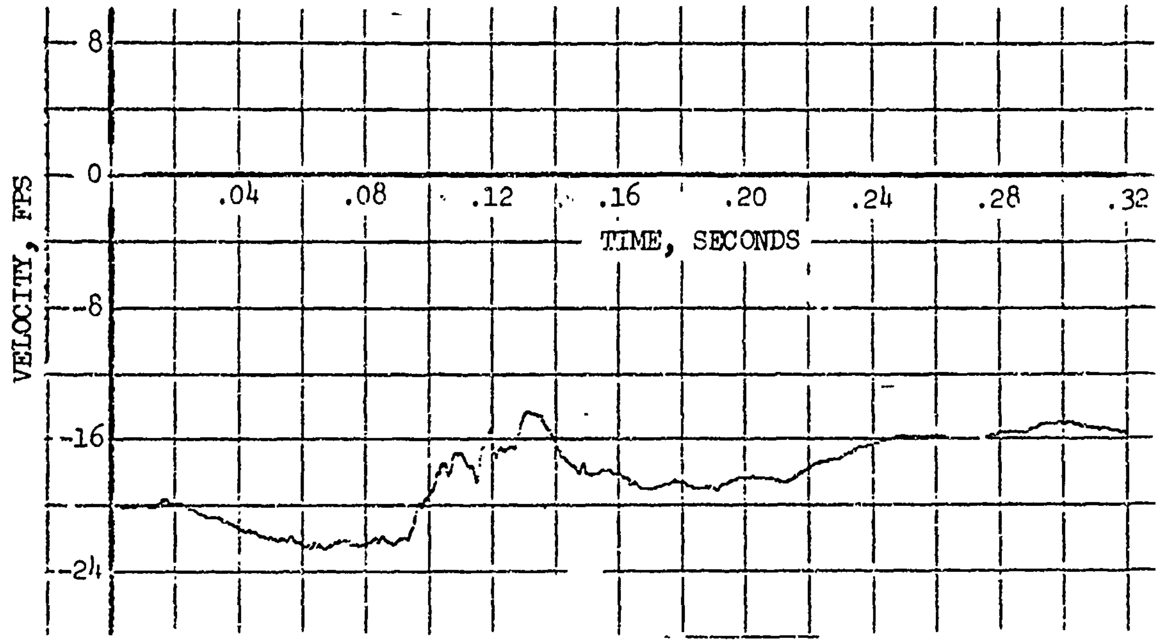


CARGO FLOOR, FWD. RIGHT, LATERAL, CHANNEL 35

Figure 64. Integrated Velocities, Cargo Floor; Forward Right.

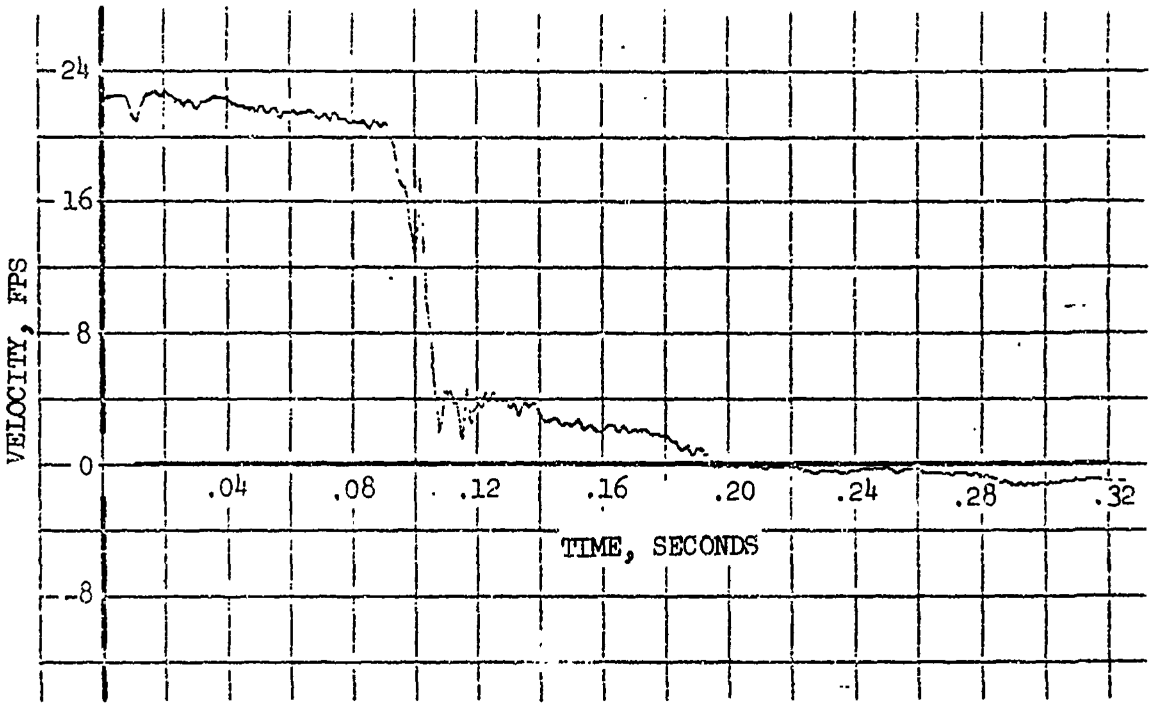


PAX FLOOR, REAR, LEFT, VERTICAL, CHANNEL 36

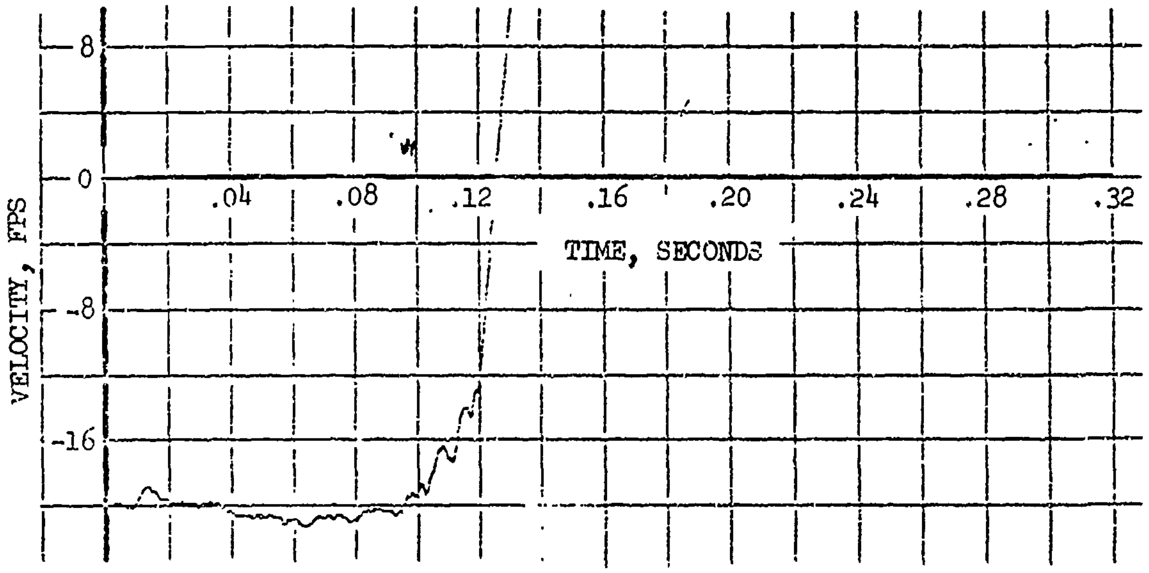


PAX FLOOR, REAR, LEFT, LATERAL, CHANNEL 37

Figure 65. Integrated Velocities, Passenger Floor, Rear Left.

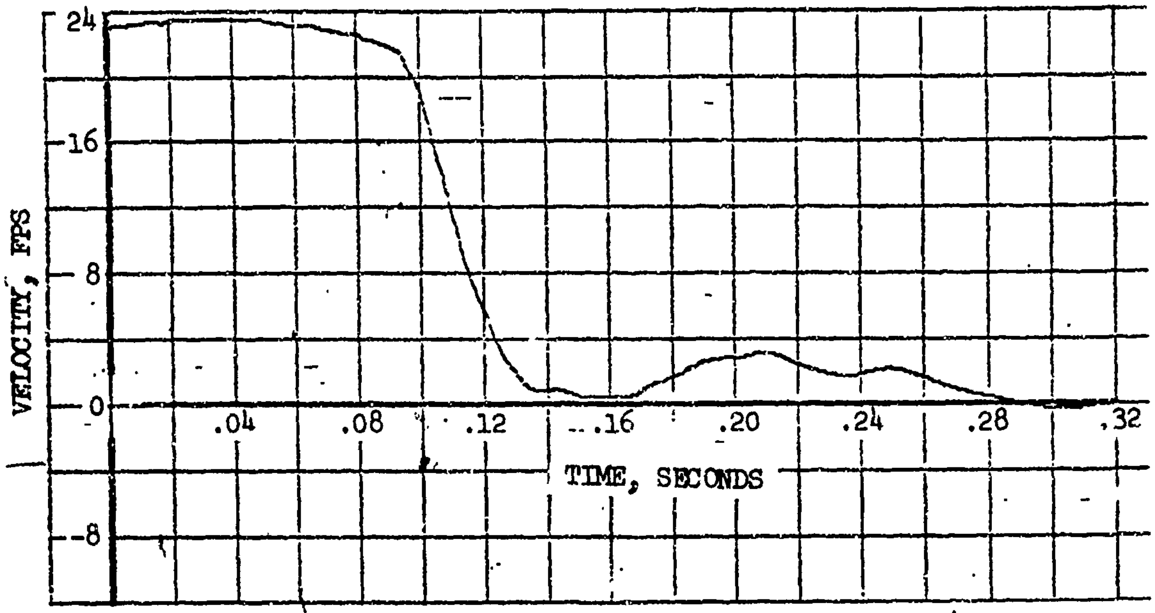


CARGO FLOOR, FWD. LEFT, VERTICAL, CHANNEL 38

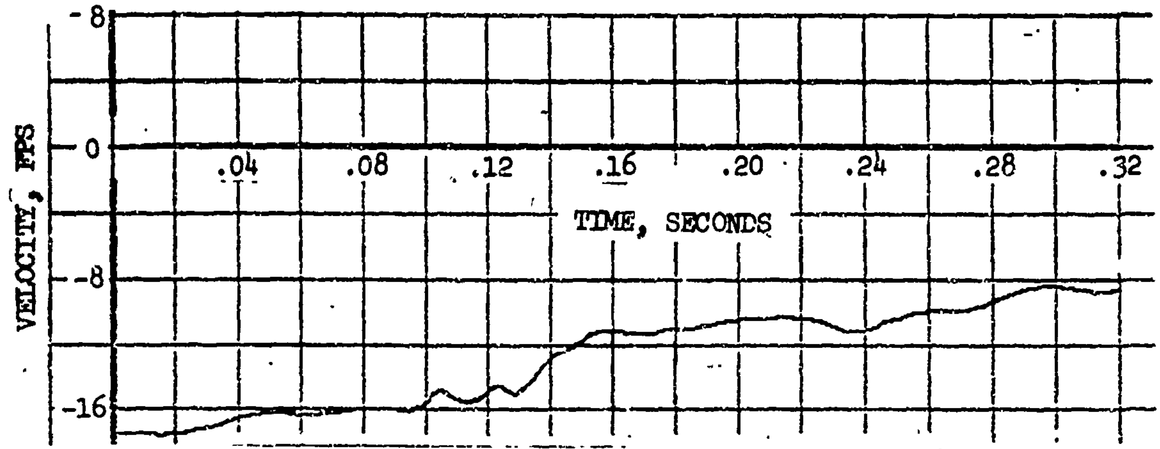


CARGO FLOOR, FWD. LEFT, LATERAL, CHANNEL 39

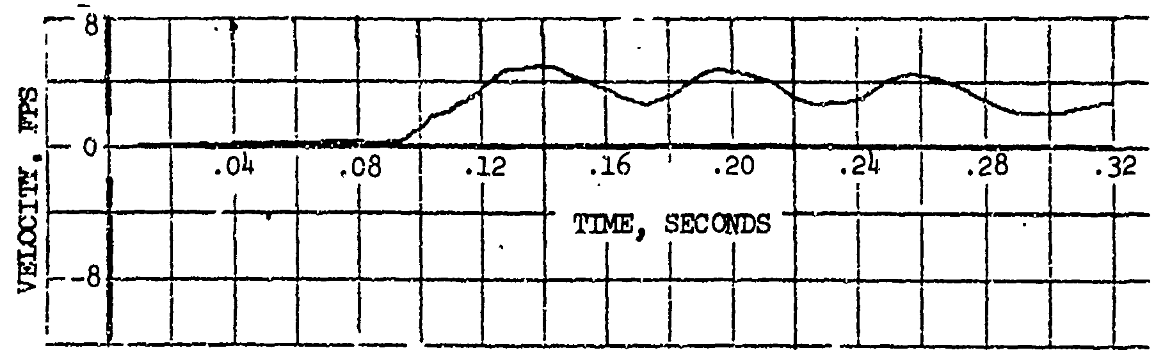
Figure 66. Integrated Velocities, Cargo Floor, Forward Left.



TRANSMISSION ROTOR HOUSING, VERTICAL, CHANNEL 40

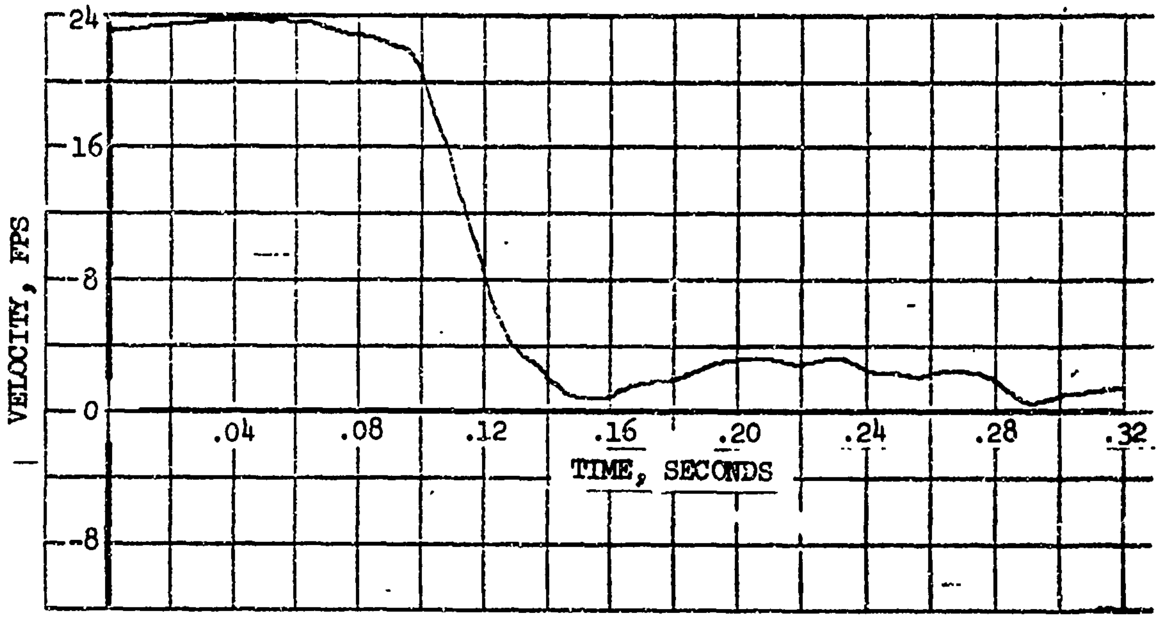


TRANSMISSION ROTOR HOUSING, LATERAL, CHANNEL 41

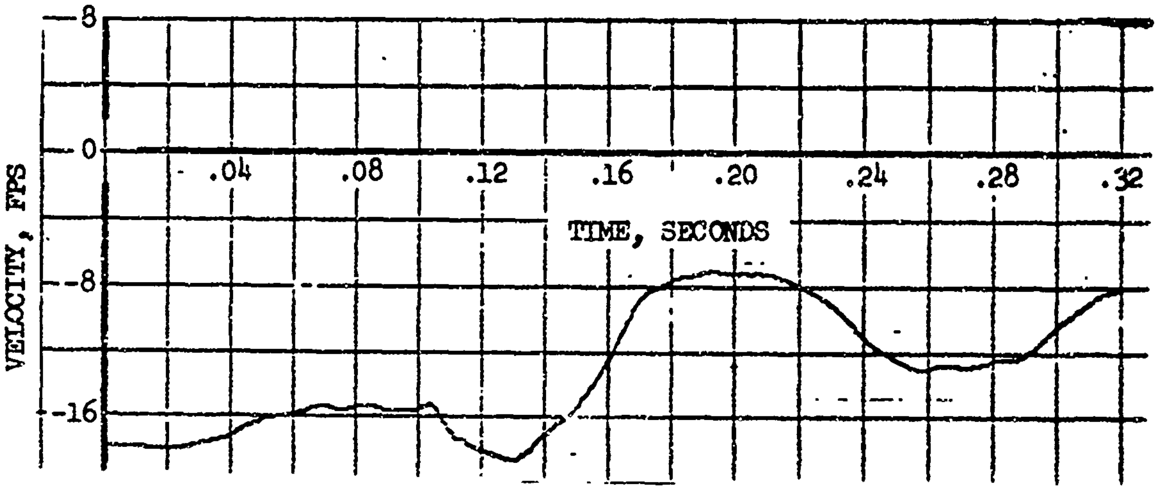


TRANSMISSION, ROTOR HOUSING, AXIAL, CHANNEL 42

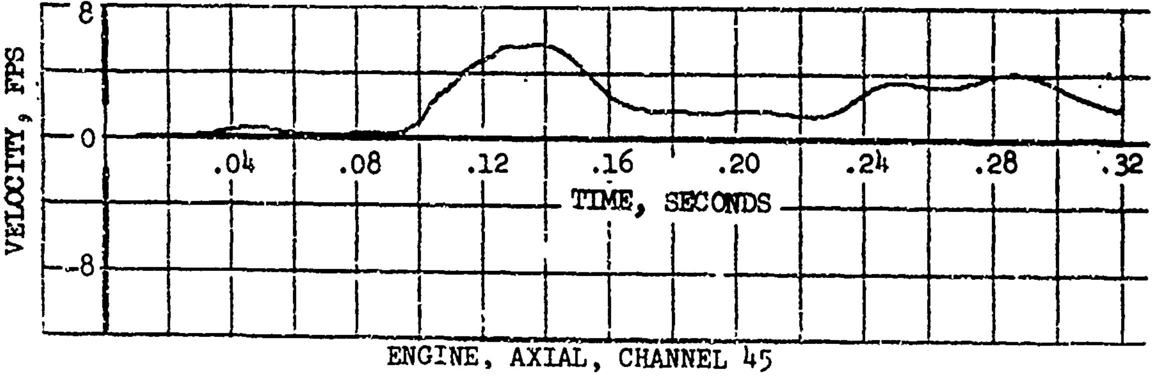
Figure 67. Integrated Velocities, Transmission Rotor Housing.



ENGINE, VERTICAL, CHANNEL 43

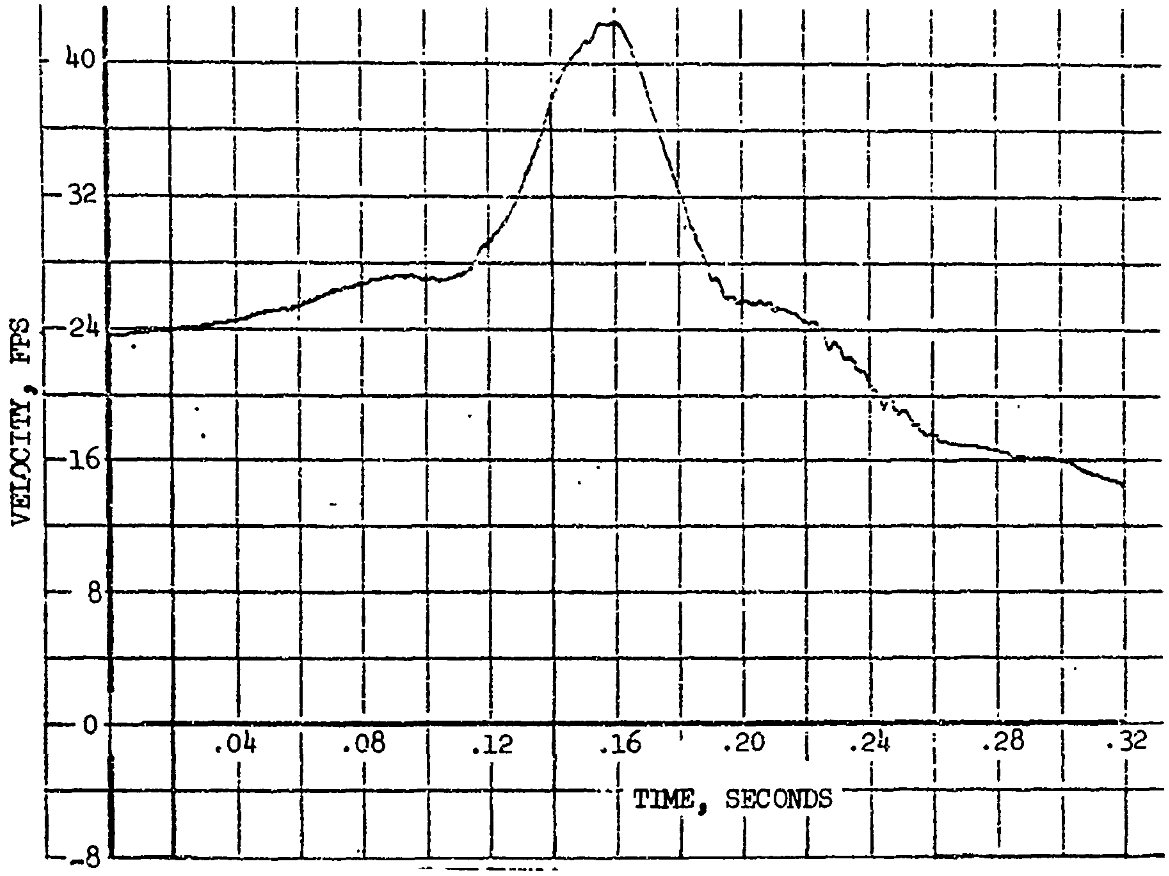


ENGINE, LATERAL, CHANNEL 44

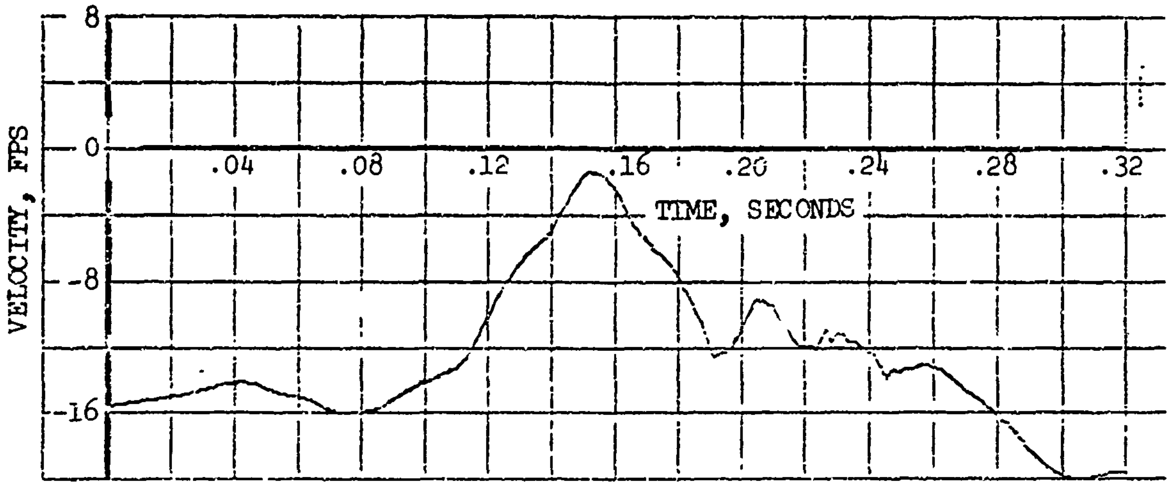


ENGINE, AXIAL, CHANNEL 45

Figure 68. Integrated Velocities, Engine.

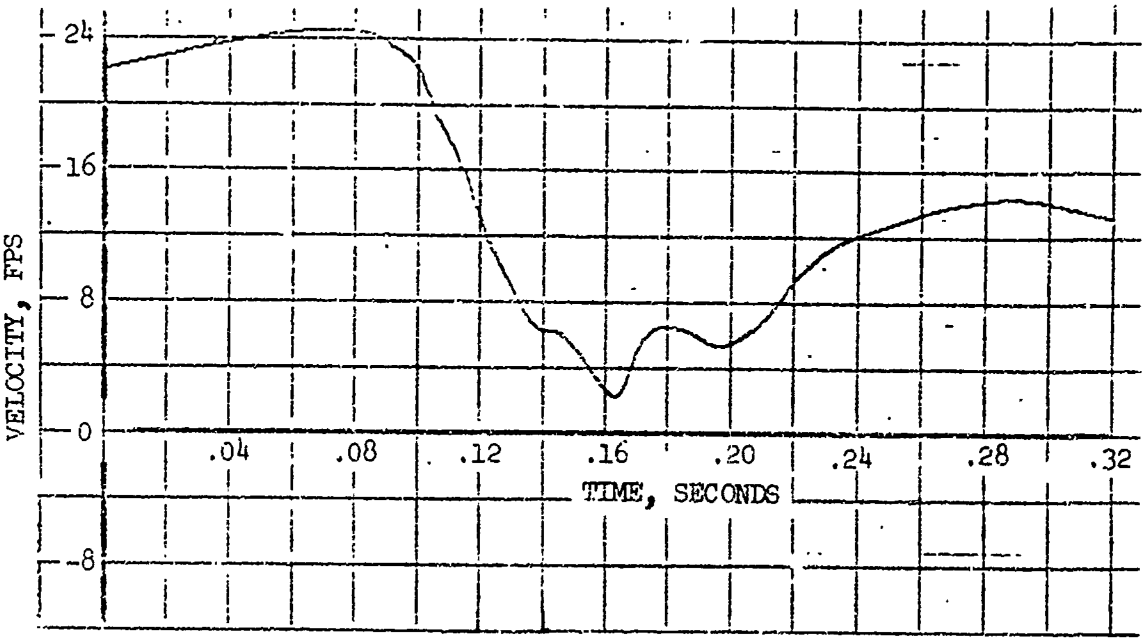


TAIL ROTOR GEARBOX, VERTICAL, CHANNEL 46

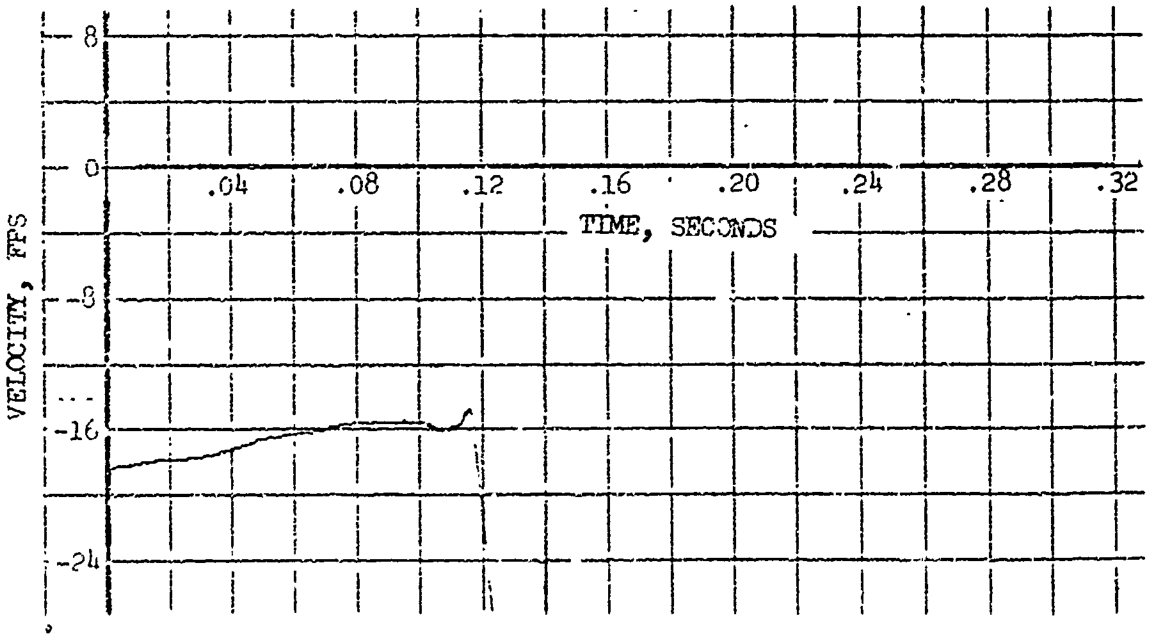


TAIL ROTOR GEARBOX, LATERAL, CHANNEL 47

Figure 69. Integrated Velocities, Tail Rotor Gearbox.

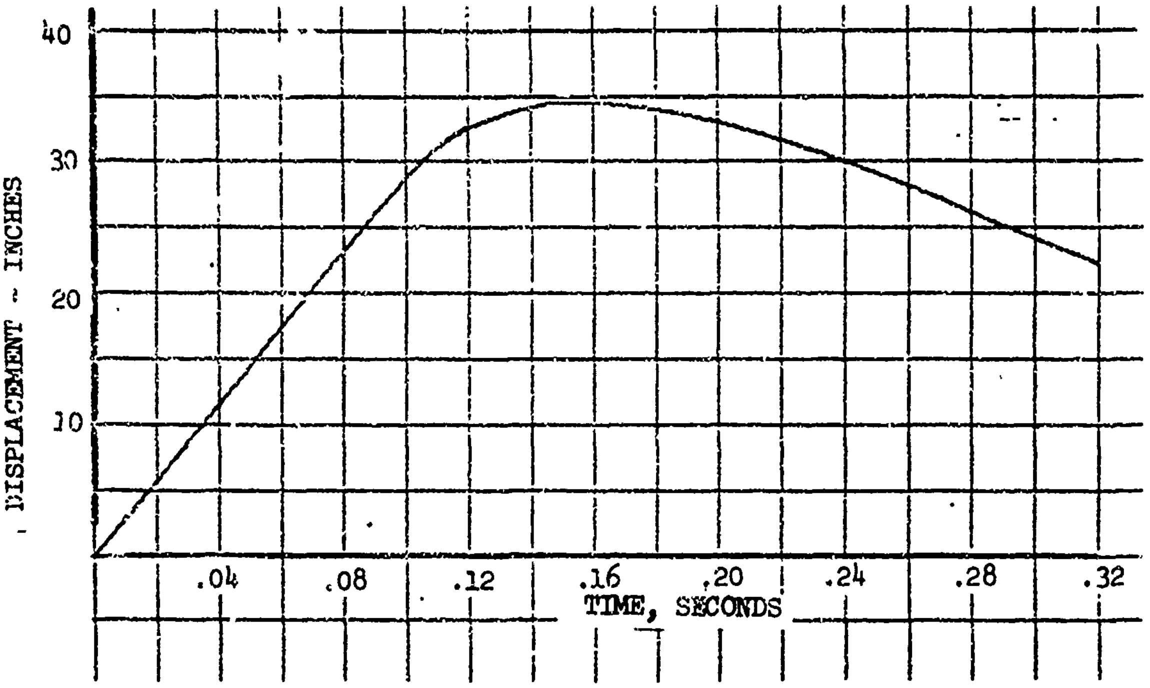


PAX PELVIC, VERTICAL, CHANNEL 48

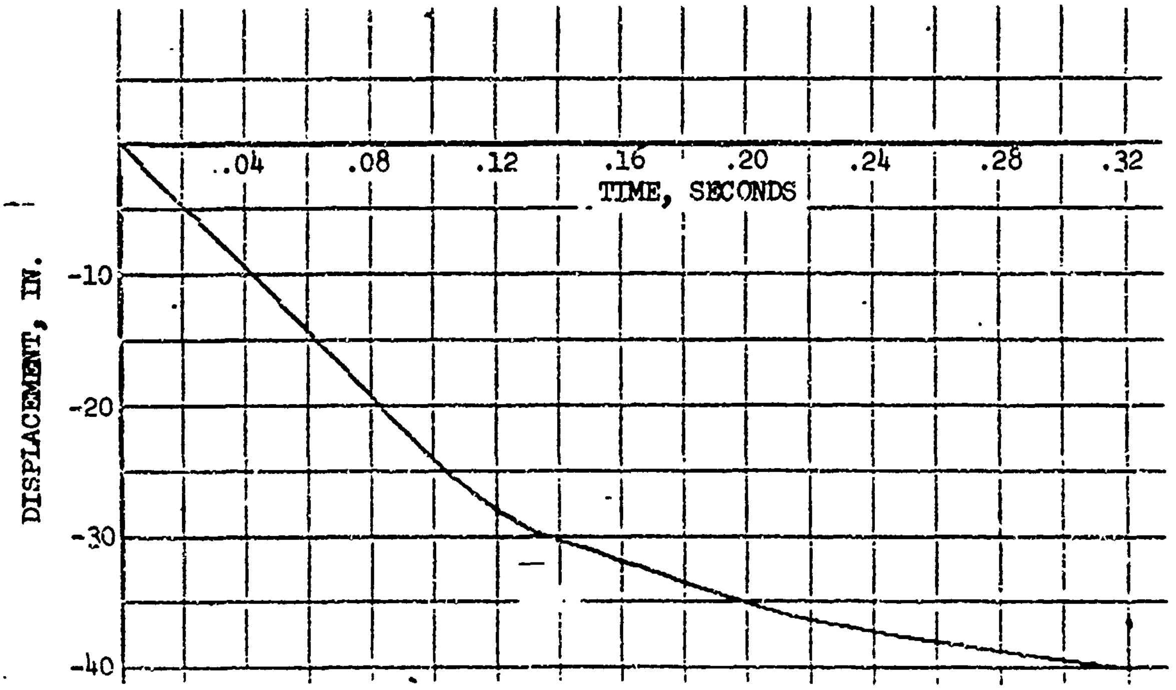


PAX PELVIC, LATERAL, CHANNEL 60

Figure 70. Integrated Velocities, Passenger Pelvic.

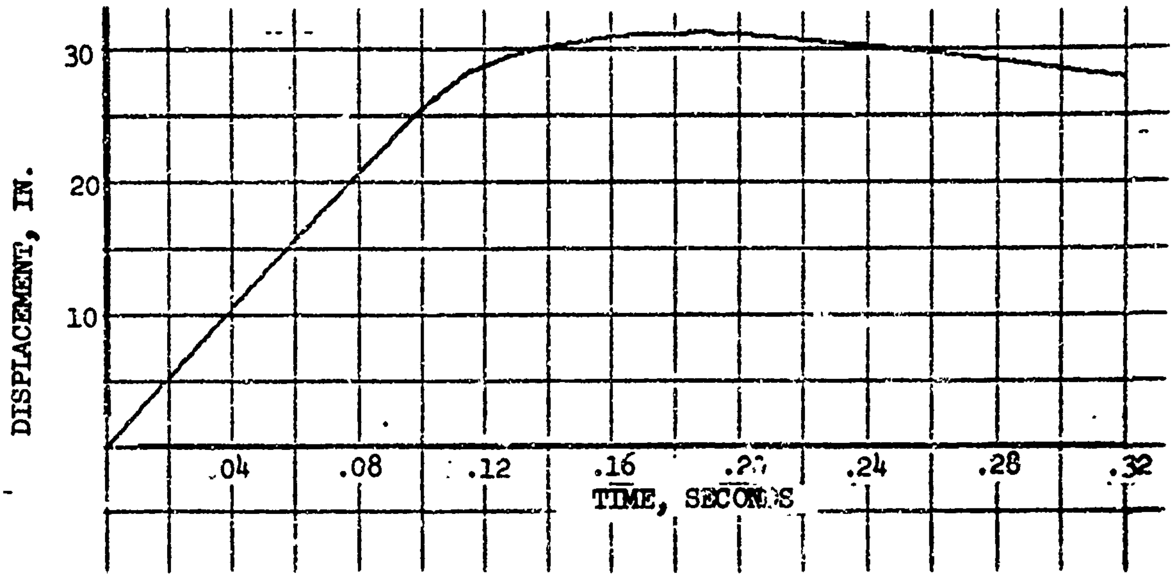


PILOT SEAT PAN, VERTICAL, CHANNEL 07

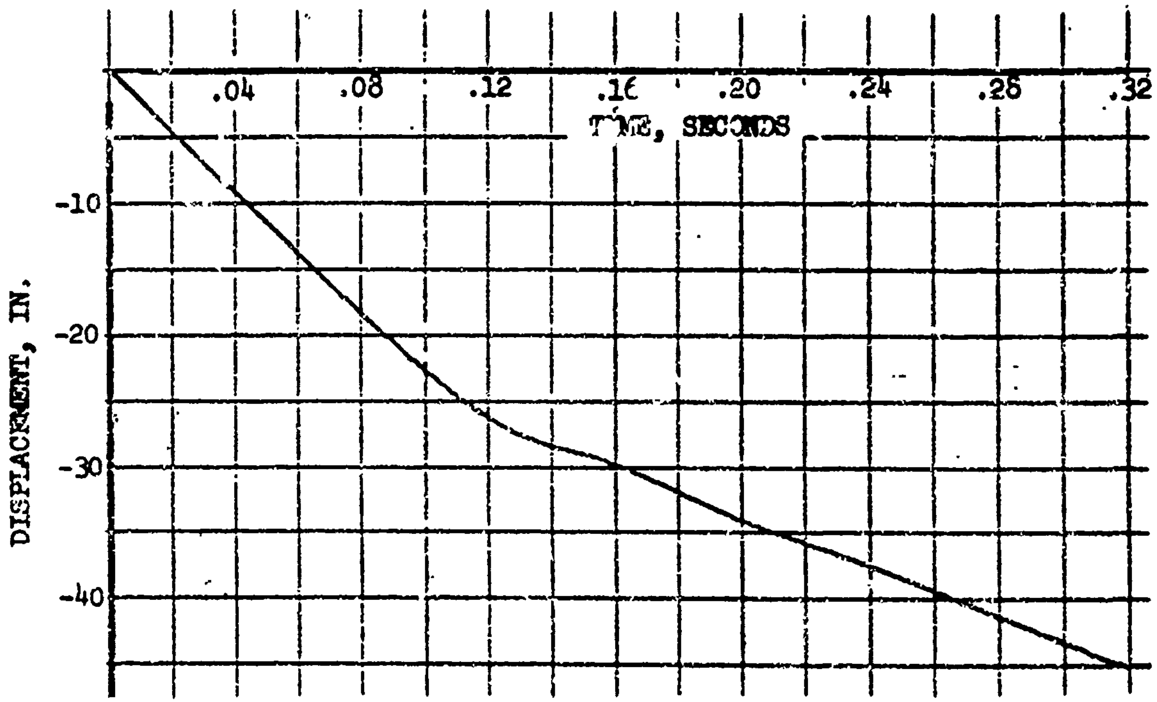


PILOT SEAT PAN, LATERAL, CHANNEL 08

Figure 71. Integrated Displacements, Pilot Seat Pan.

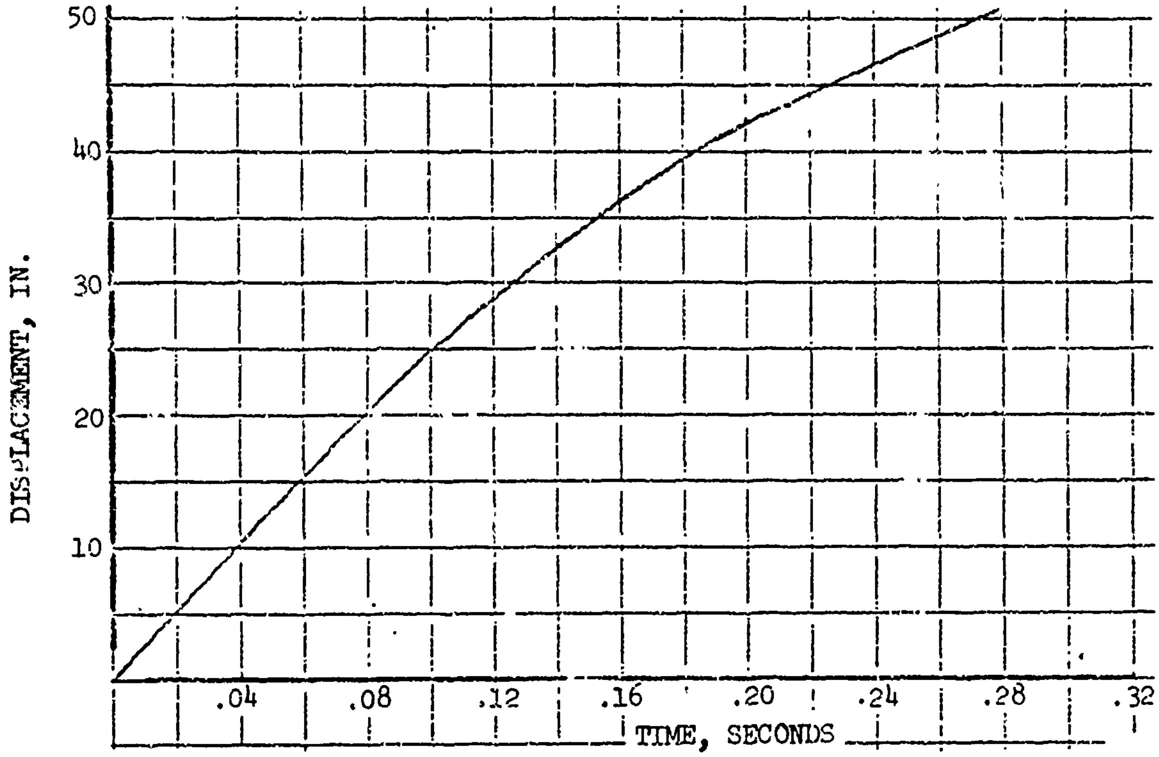


COPILOT SEAT PAN. VERTICAL, CHANNEL 09

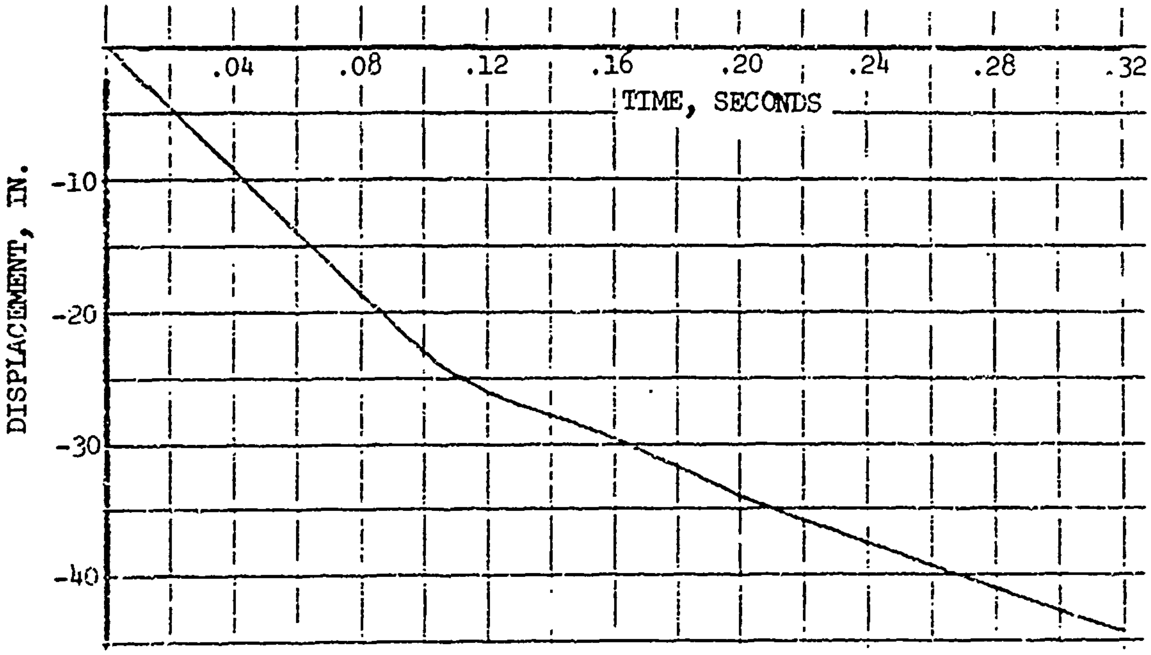


COPILOT SEAT PAN, LATERAL, CHANNEL 10

Figure 72. Integrated Displacements, Copilot Seat Pan.

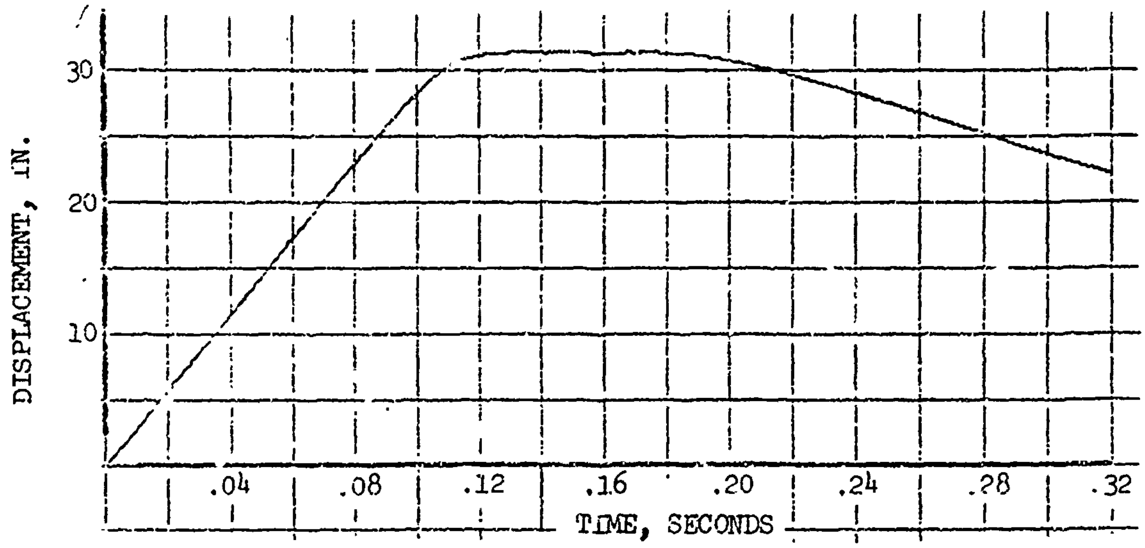


FLOOR, COPILOT LOC., VERTICAL, CHANNEL 30

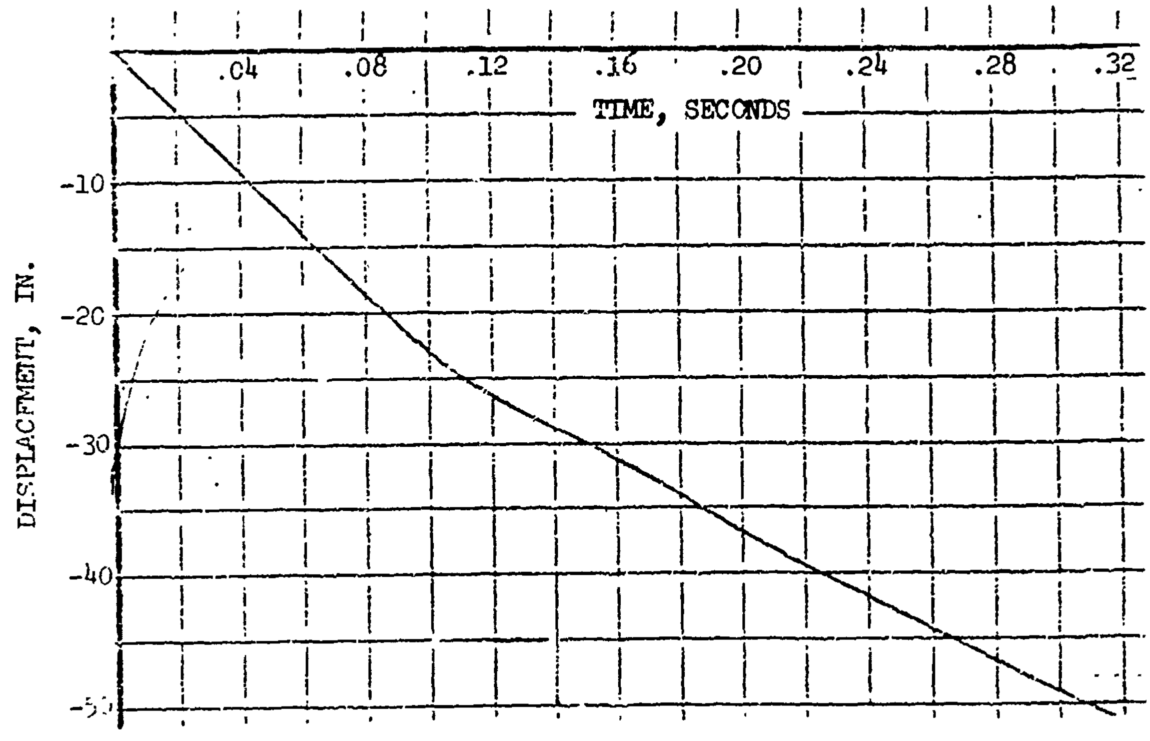


FLOOR, COPILOT LOC., LATERAL, CHANNEL 31

Figure 73. Integrated Displacements, Floor, Copilot Location.

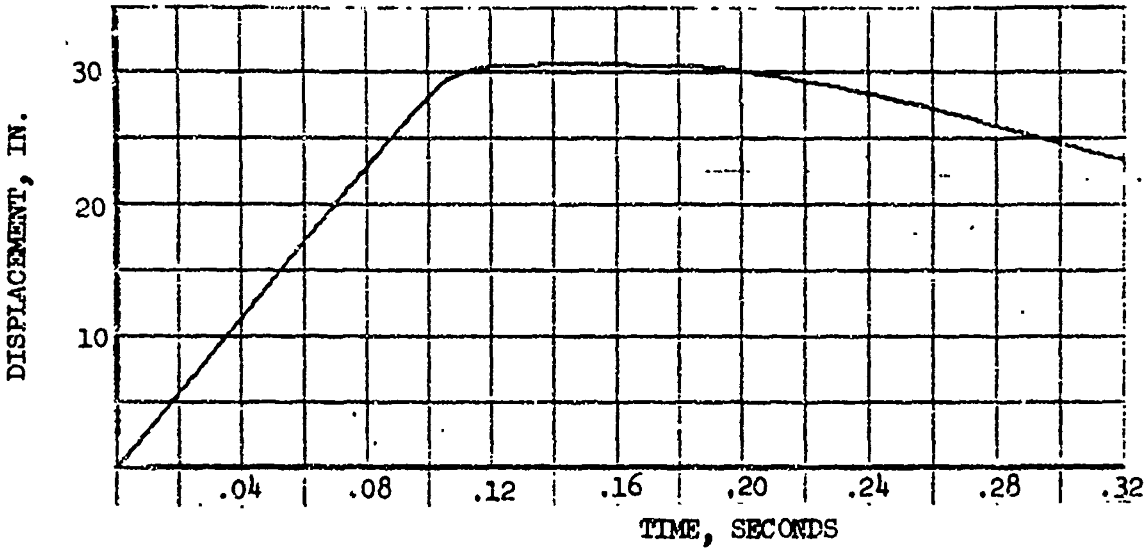


FLOOR, PILOT LOC., VERTICAL, CHANNEL 32

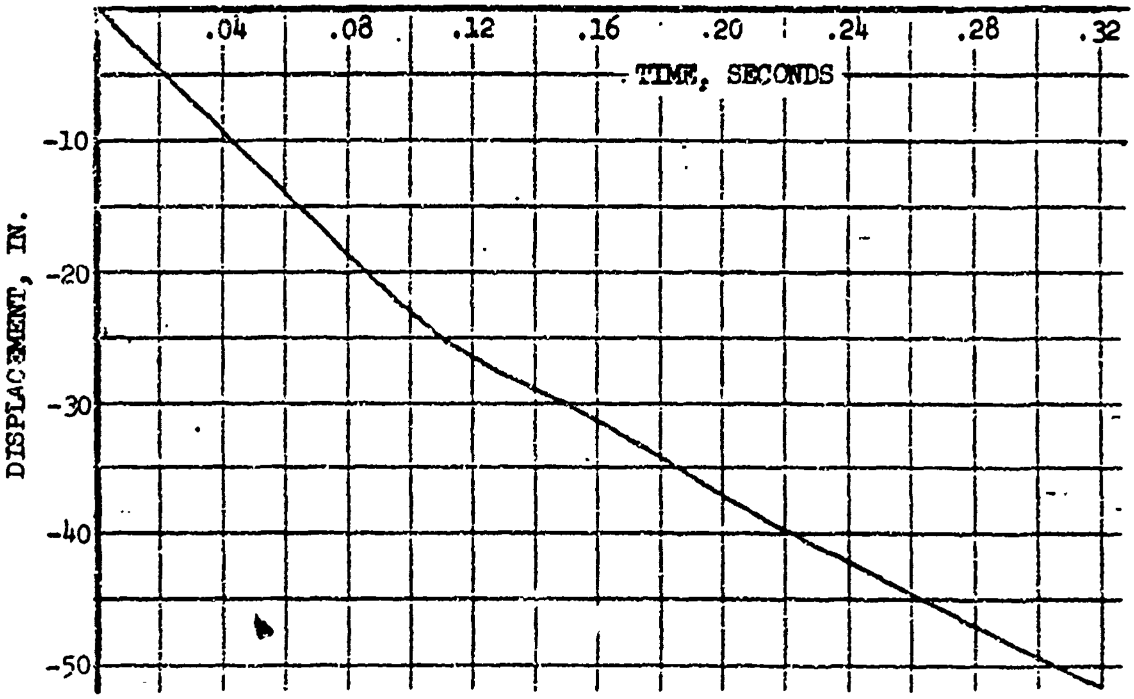


FLOOR, PILOT LOC., LATERAL, CHANNEL 33

Figure [illegible]. Integrated Displacements, Floor, Pilot Location.

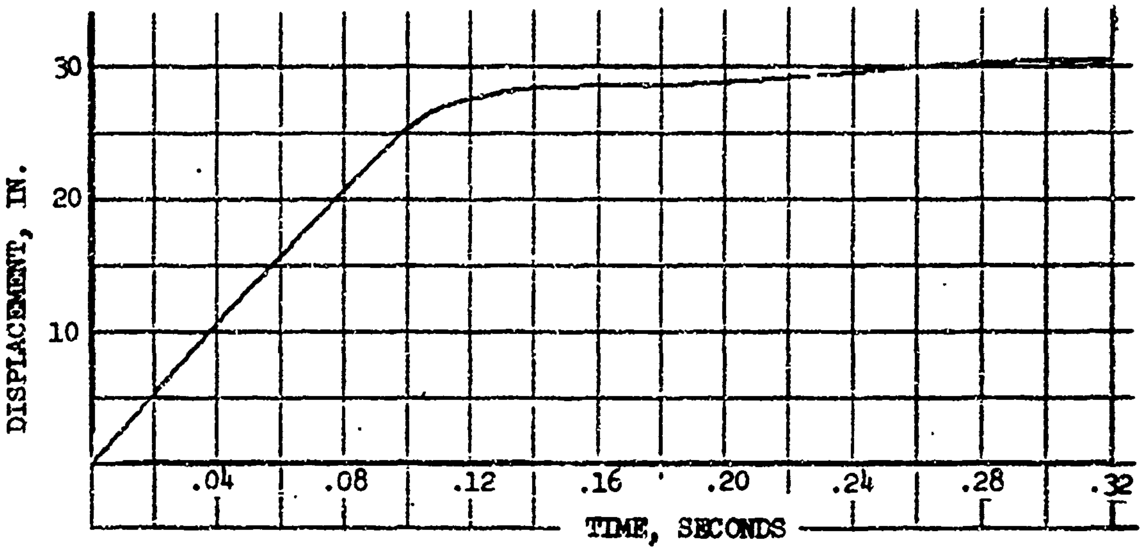


CARGO FLOOR, FWD. RIGHT, VERTICAL, CHANNEL 34

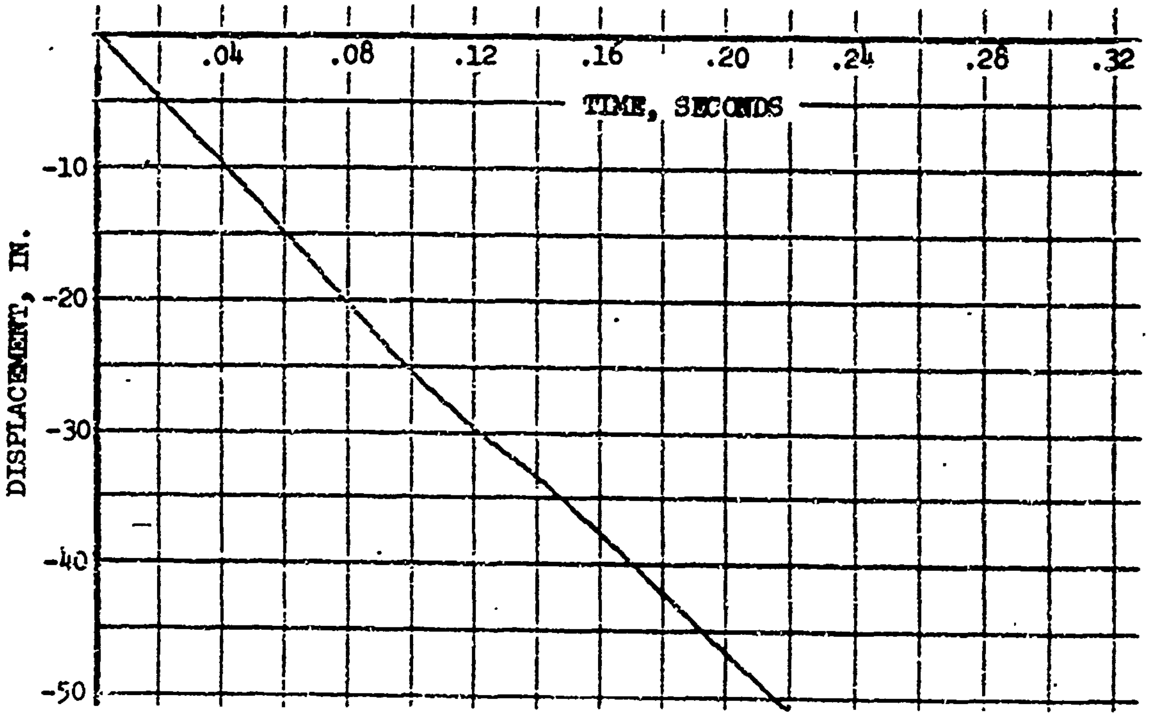


CARGO FLOOR, FWD. RIGHT, LATERAL, CHANNEL 35

Figure 75. Integrated Displacements, Cargo Floor Forward Right.

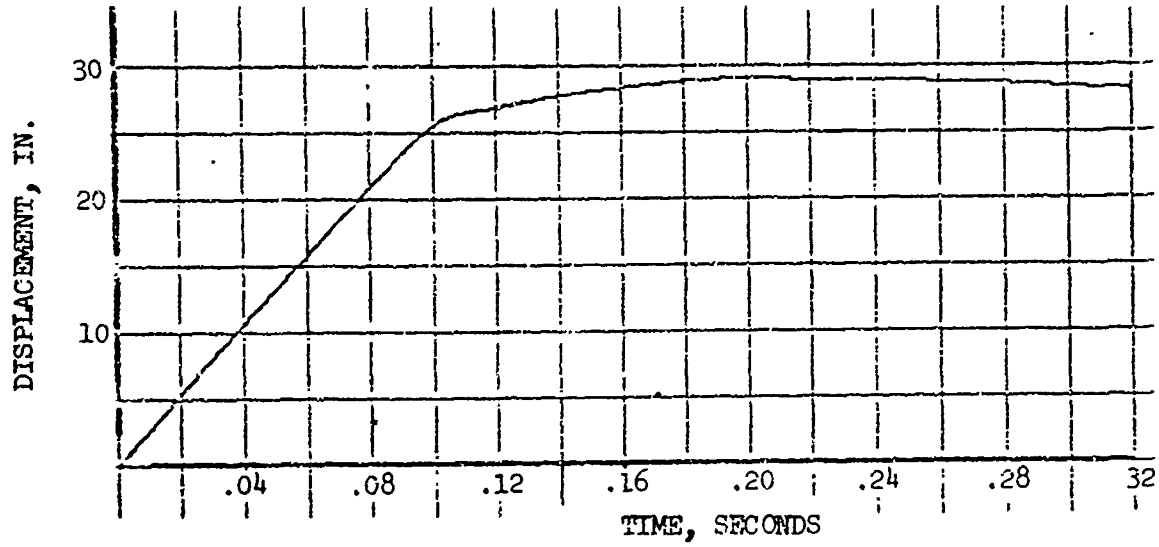


PAX FLOOR, REAR, LEFT, VERTICAL, CHANNEL 36

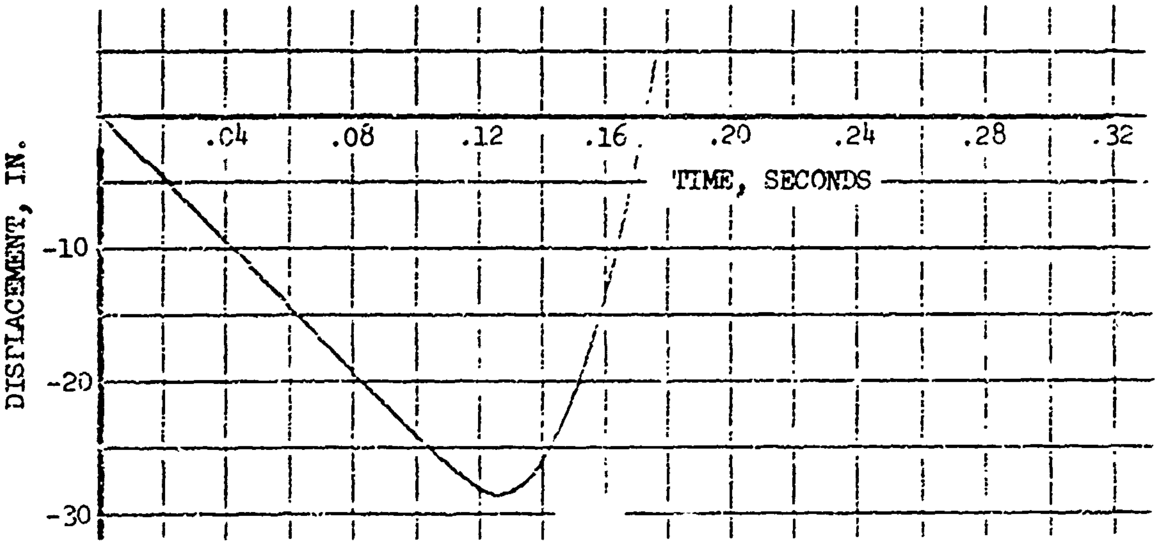


PAX FLOOR, REAR, LEFT, LATERAL, CHANNEL 37

Figure 76. Integrated Displacements, Passenger Floor Rear Left.



CARGO FLOOR, FWD. LEFT, VERTICAL, CHANNEL 38



CARGO FLOOR, FWD. LEFT, LATERAL, CHANNEL 39

Figure 77. Integrated Displacements, Cargo Floor Forward Left.

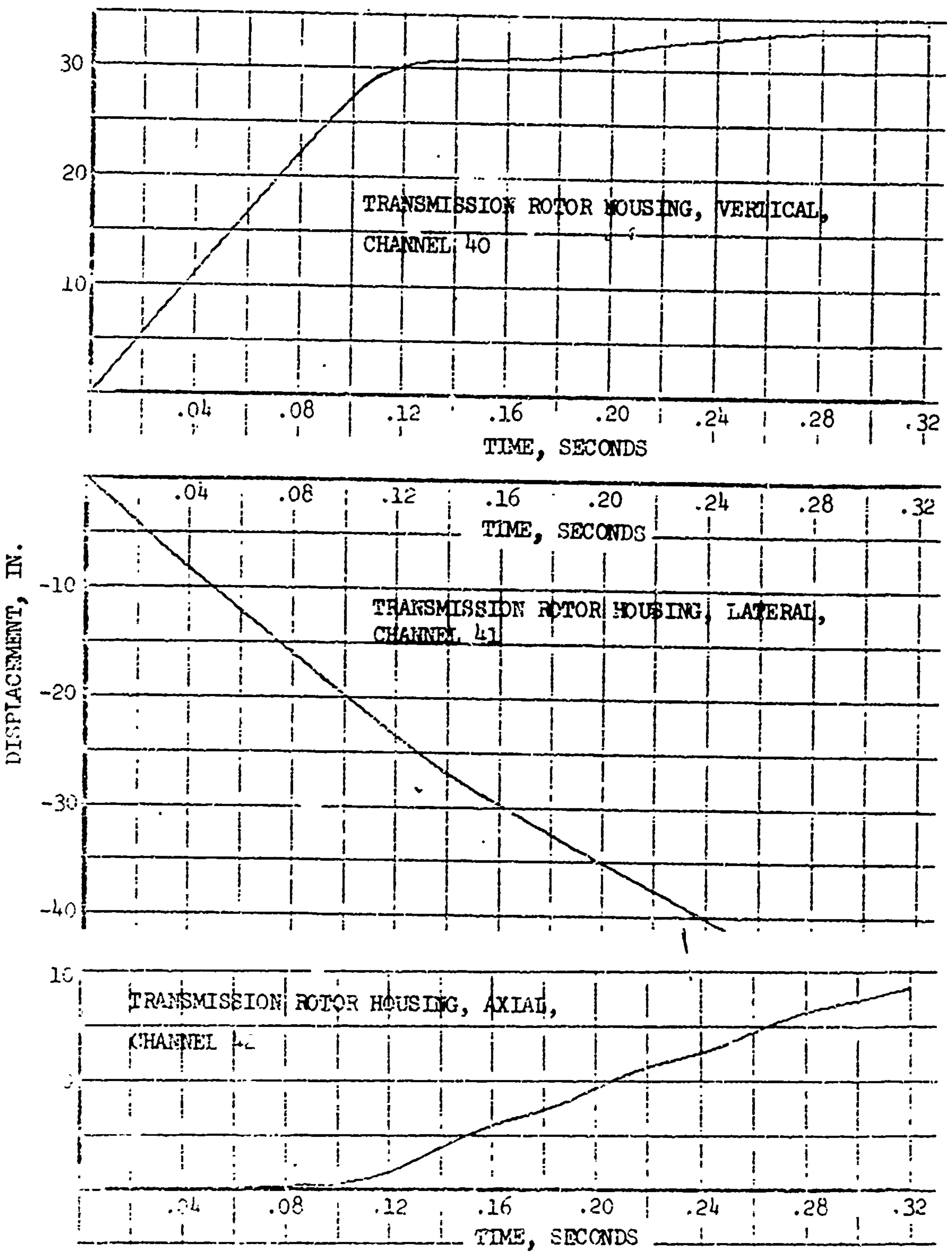


Figure [illegible]. Integrated Displacements, Transmission Rotor Housing.

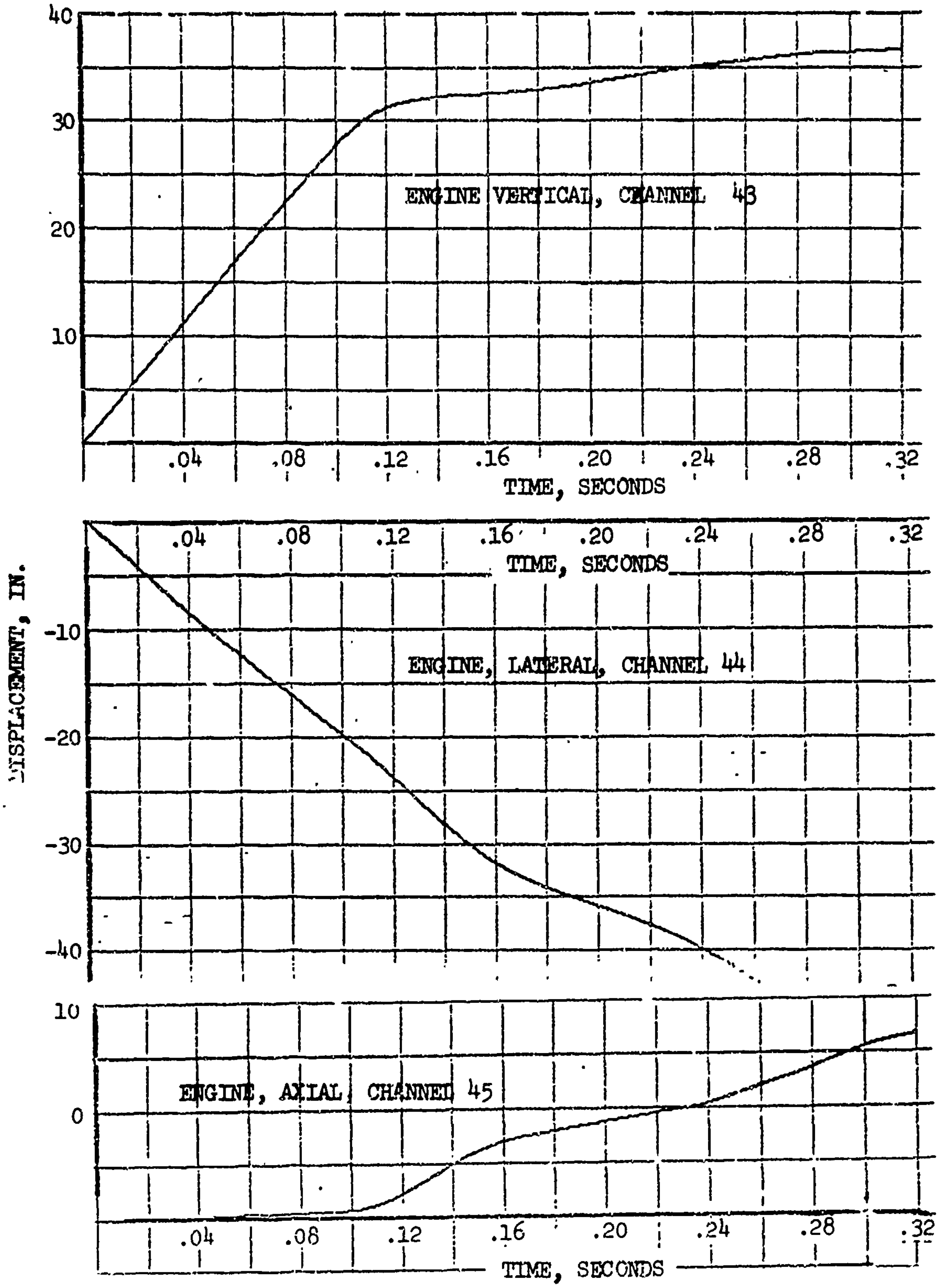


Figure 79. Integrated Displacements, Engine.

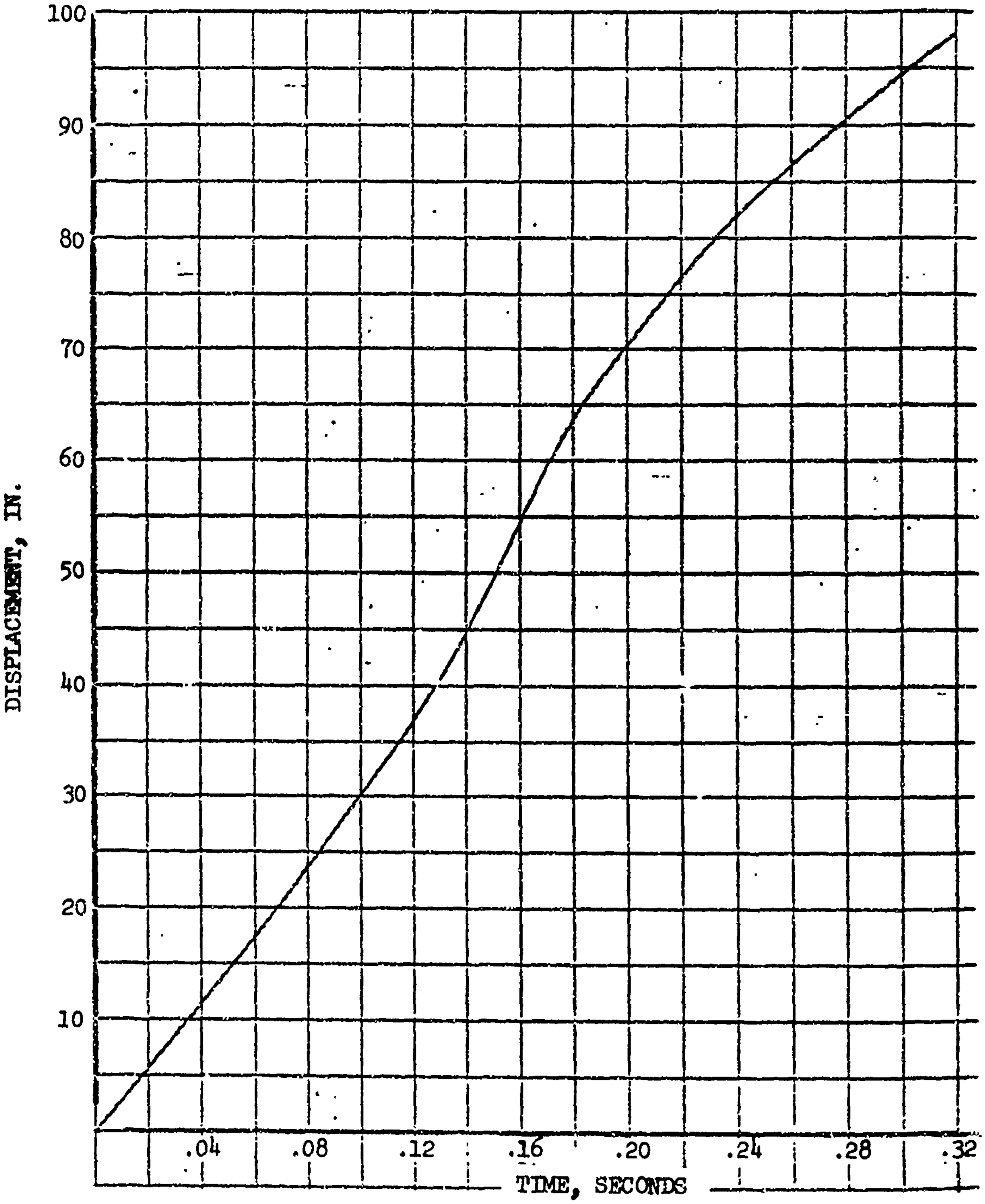


Figure 80. Integrated Displacement, Tail Rotor Gearbox, Vertical, Channel 46.

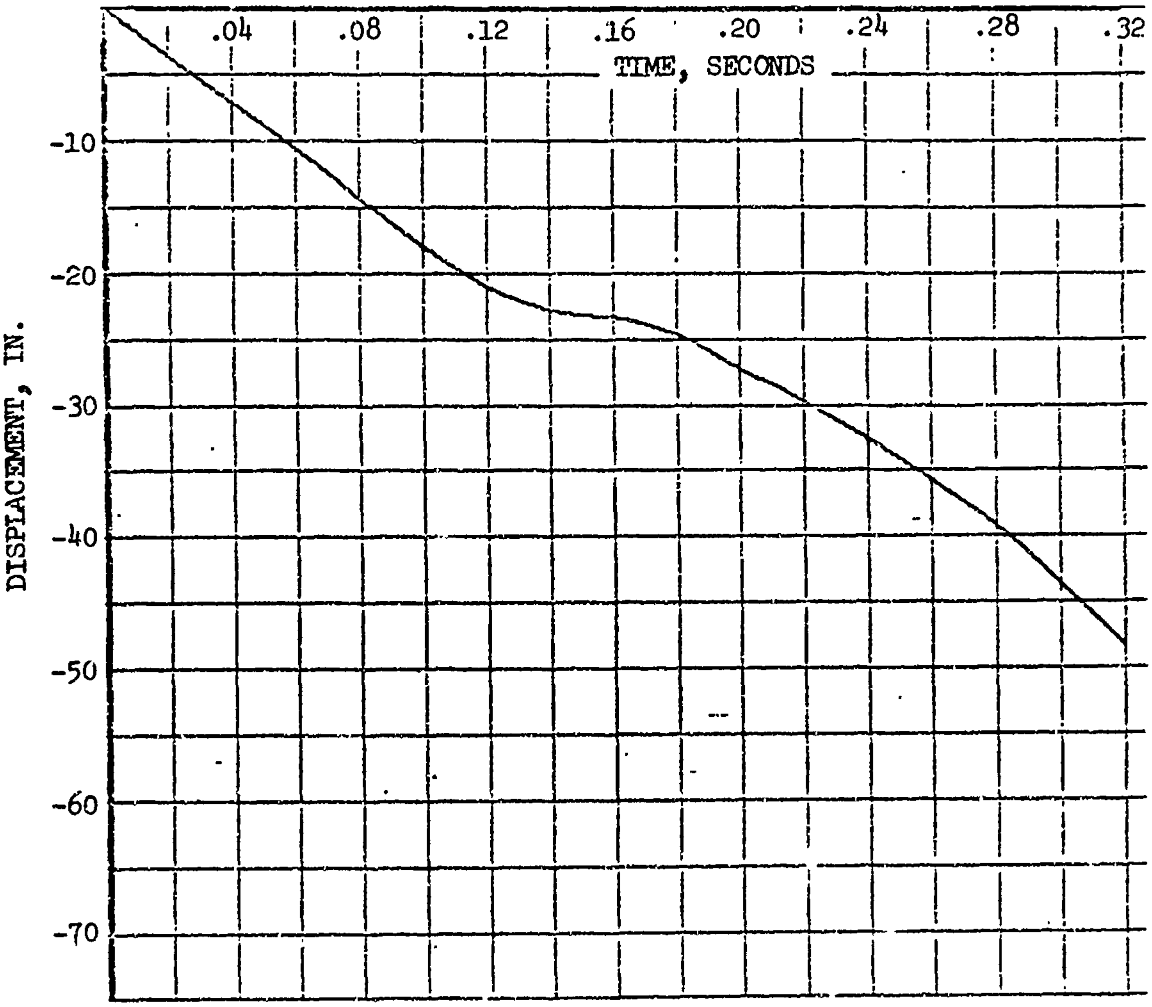
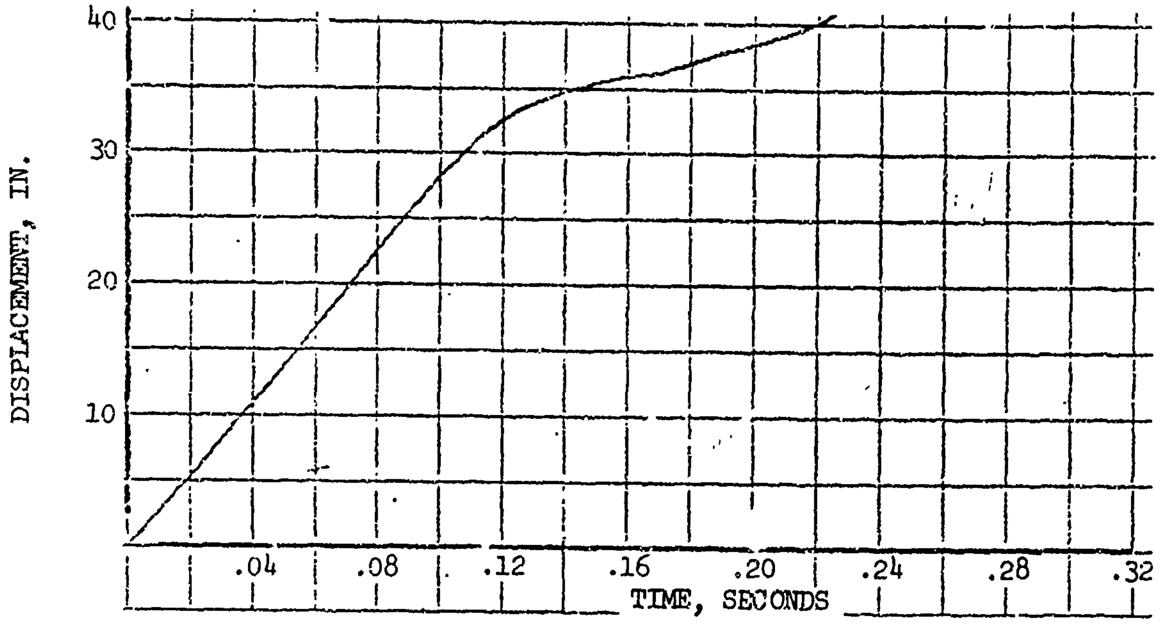
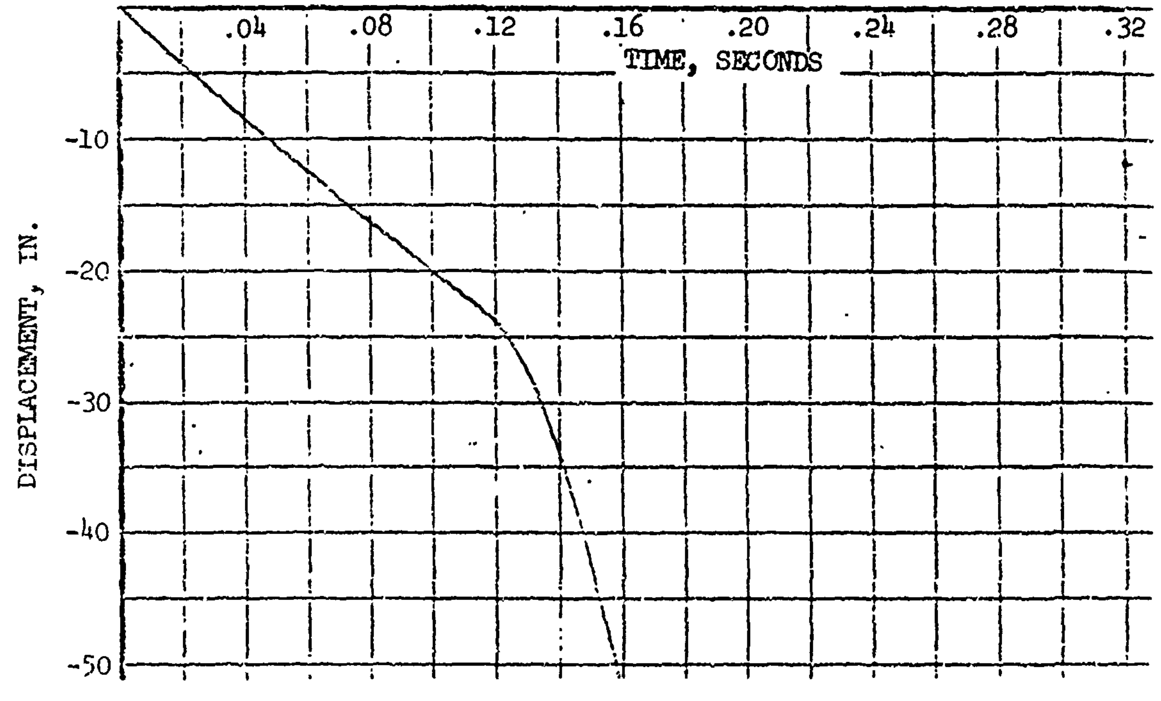


Figure 81. Integrated Displacement, Tail Rotor Gearbox, Lateral, Channel 47.



PAX PELVIC, VERTICAL, CHANNEL 48



PAX PELVIC, LATERAL, CHANNEL 60

Figure 82. Integrated Displacement, Passenger Pelvic.

*Initial impact

SEQUENCE	EVENT	SECONDS
0	FIRST FLASH	0
1	ACTUAL SWING RELEASE	.1007
2	SECOND FLASH	1.163
3	VERTICAL DROP RELEASE	1.207
4	IMPACT LEFT FRONT SKID	1.653*
5	FULL IMPACT LEFT SKID	1.664
6	IMPACT RIGHT FRONT SKID	1.698
7	FULL IMPACT RIGHT SKID	1.705
8	FUSELAGE IMPACT	1.762
9	BOOM START TO BEND	1.877
10	BOOM TIP IMPACT	2.055
11	SECOND FUSELAGE IMPACT	2.624
12	END OF LATERAL MOTION	2.868

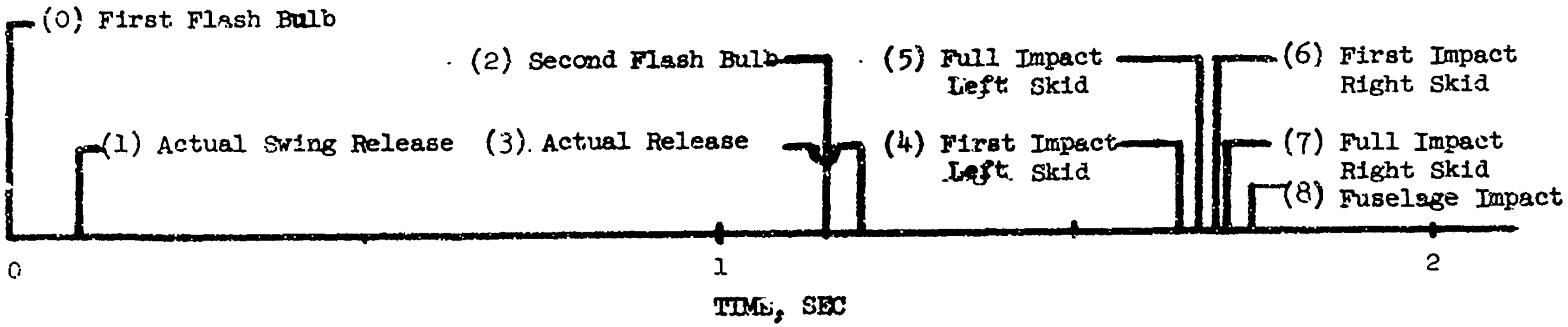
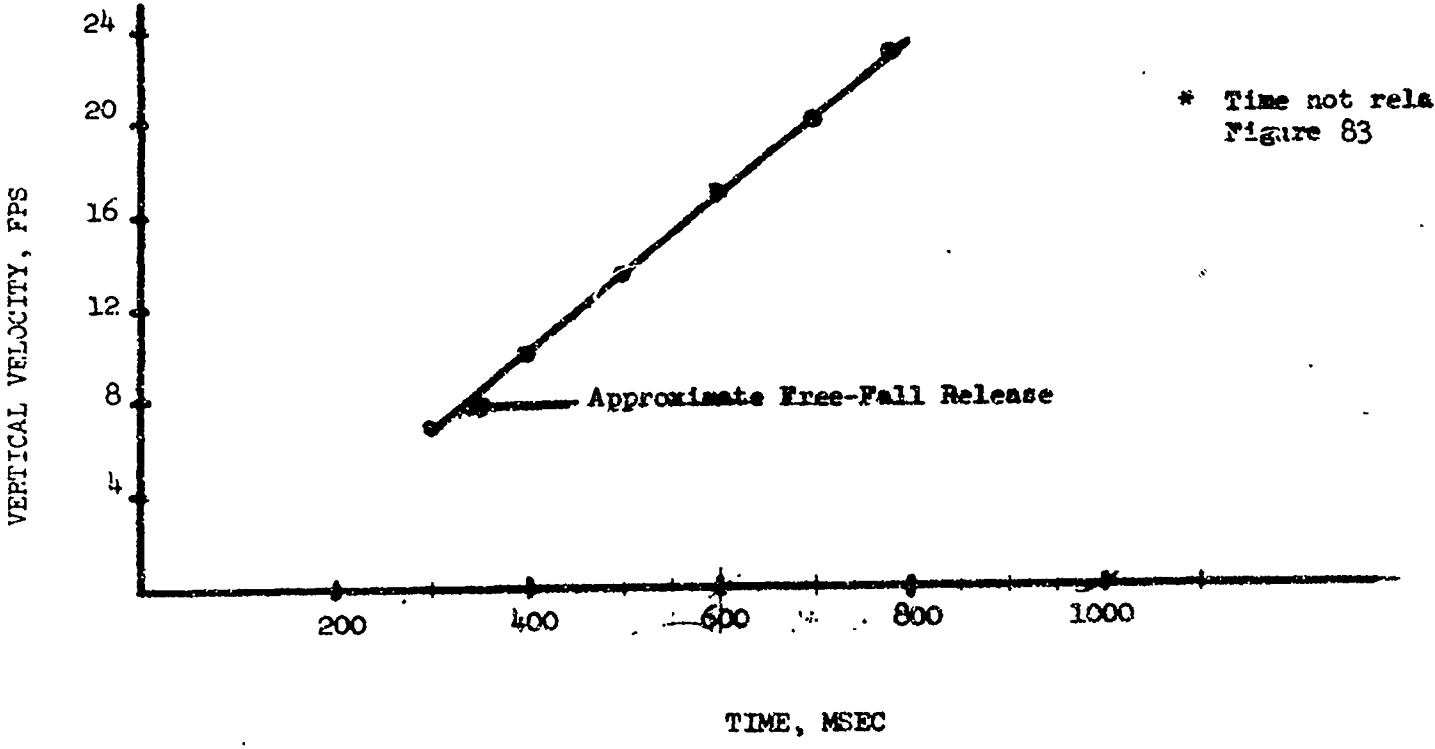
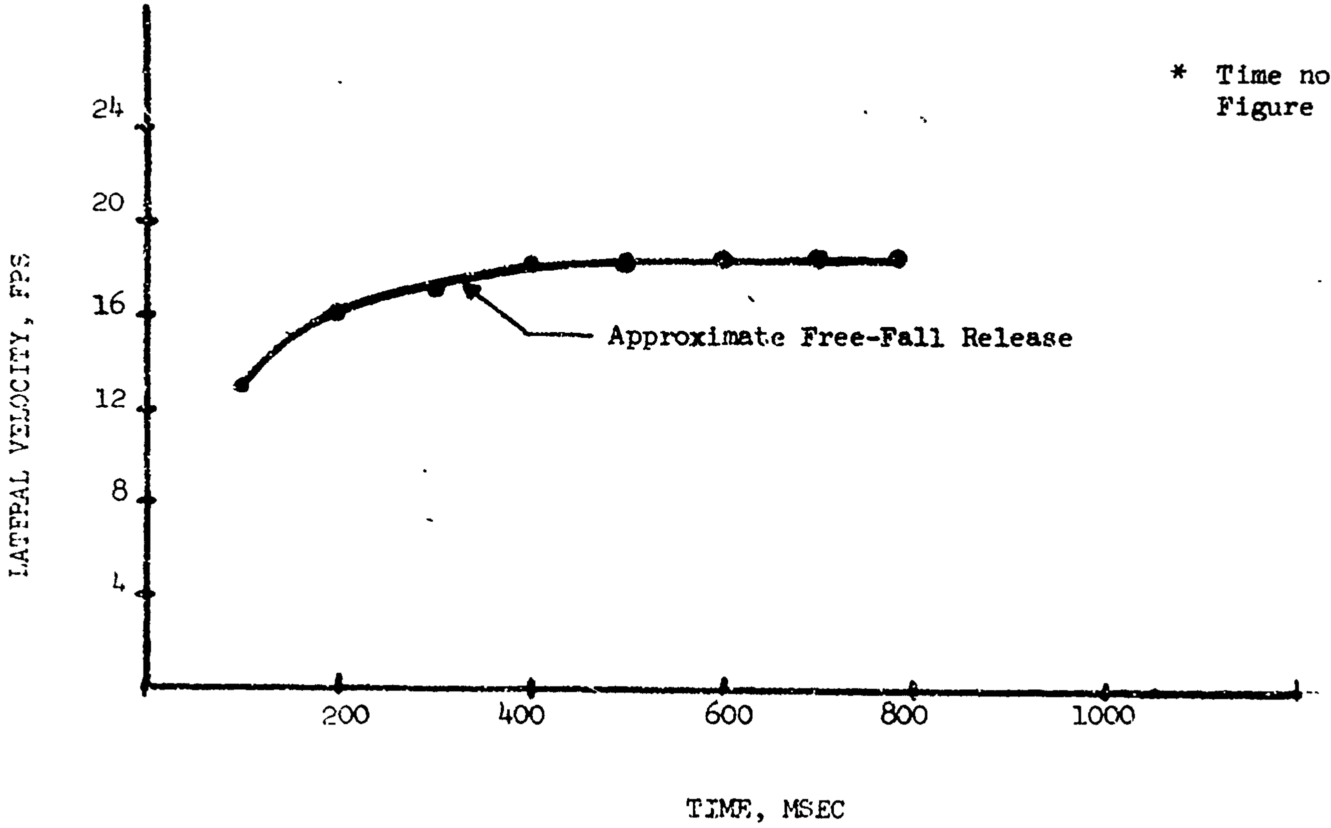


Figure 83. Sequence of Events - Film Data.



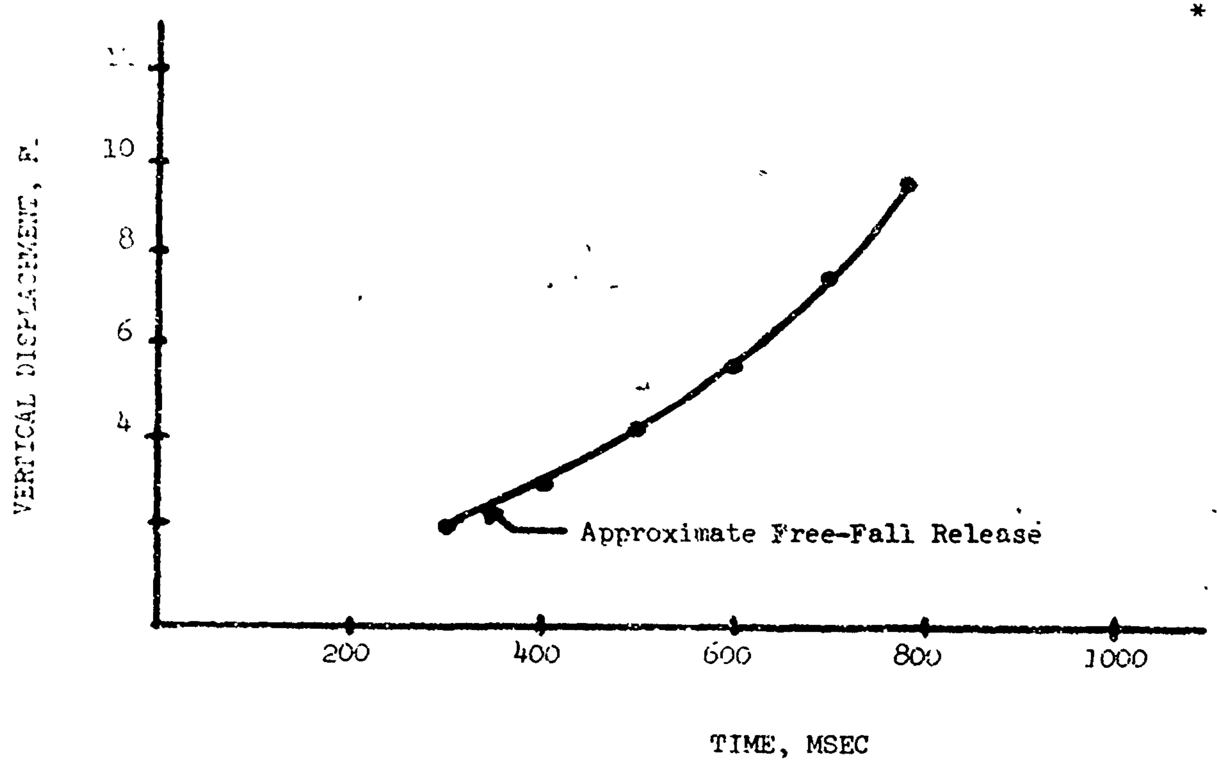
* Time not related to Figure 83

Figure 84. Vertical Impact Velocity - Film Data.



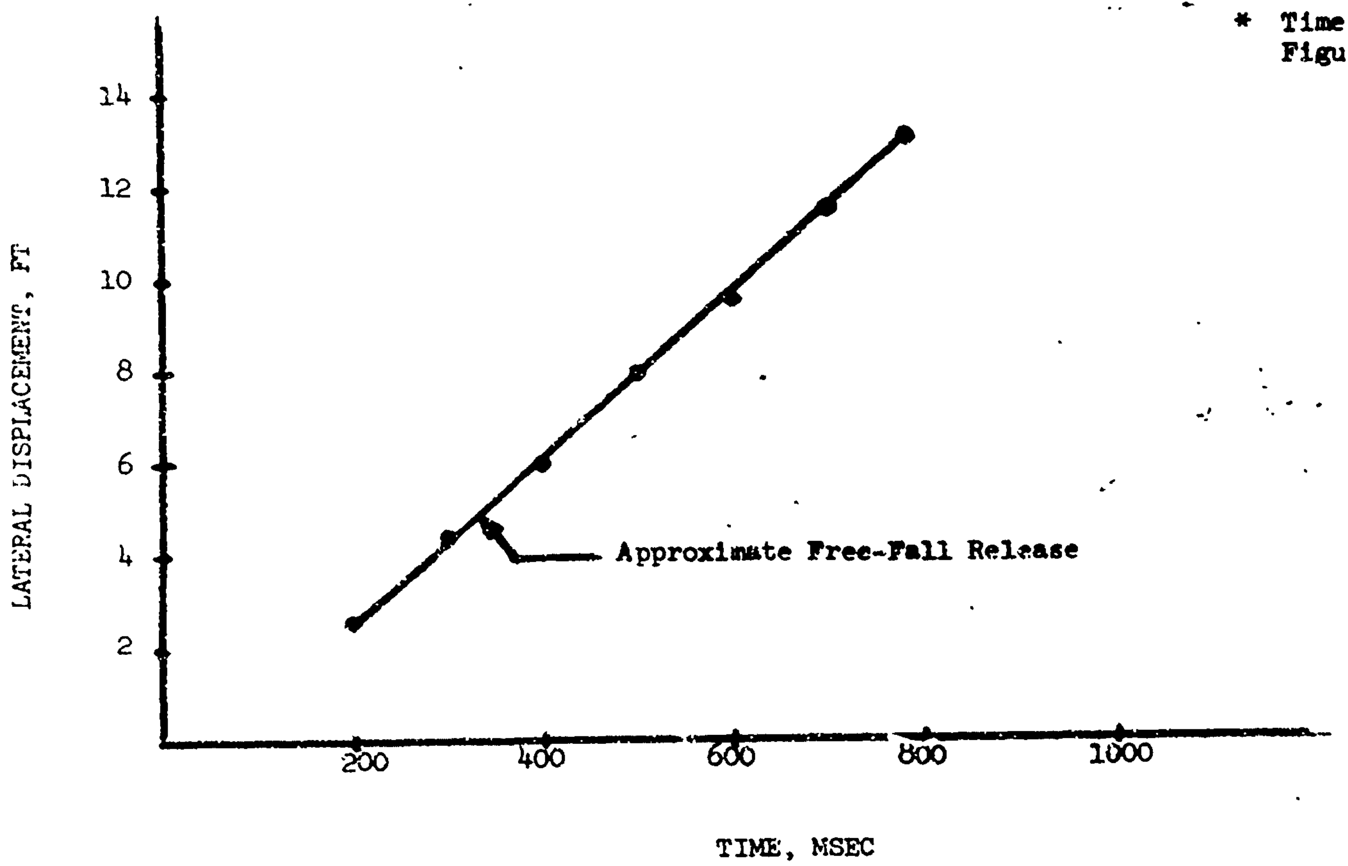
* Time not related to Figure 83

Figure 85. Lateral Impact Velocity - Film Data



* Time not related to Figure 83

Figure 86. Vertical Displacement - Film Data



* Time not related to Figure 83

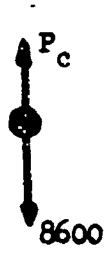
Figure 87. Lateral Displacement - Film Data

CALCULATED TEST IMPACT VELOCITIES

APPROACH NO. 1

1. **Position (1)** Cable Load (Pc)

$Pc = 8600$ lb



2. **Position (2)** 40° Rotation for Initial Swing Release

$Pc = 8600 \cos 40^{\circ}$

$Ps = 8600 \sin 40^{\circ}$

$\cos 40^{\circ} = .77$

$\sin 40^{\circ} = .64$

$Pc = 8600 \times .77 = 6700$ lb

$Ps = 8600 \times .64 = 5500$ lb

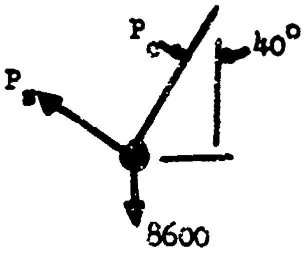
3. **Position (3)** 24° Rotation; Release for Free Fall

$Pc = 8600 \times \cos 24^{\circ}$

$Pc = 8600 \times .91$

$Pc = 7800$ lb

$K.E. = P.E.$



$$\frac{W}{g}\frac{V^2}{2} = Wh$$

$$V = \sqrt{(2gh)}$$

$$V = \left[2 \times 32.2\ (18.2 - 11.6)\right]^{\frac{1}{2}}$$

$V = 20.2$ fps

$V_h = 20.2\ (.92) = 18.6$

$V_v = V\ (.405) = 8.20$

4. Position (4)

$$h_4 = 50 \sin 10^\circ + 48 \cos 10^\circ$$

$$\sin 10^\circ = .1736$$

$$\cos 10^\circ = .9848$$

$$h_4 = (50 \times .1736 + 48 \times .9848)\ 1/12$$

$$h_4 = (8.63 + 47.5)\ 1/12$$

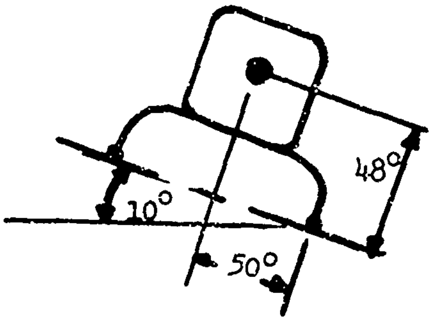
$$h_4 = 4.65 \text{ ft.}$$

$$h_4 = \tfrac{1}{2}\ gt^2 + V_v t = 4.65$$

$$h = 11.6 - 4.65 = 6.95$$

$$16.1\ t^2 + 8.2\ t - 6.95 = 0$$

$$t = \frac{-b + \sqrt{b^2 - 4ac}}{2a}$$



$$t = .5 \text{ sec}$$

$$V = \sqrt{V_o^{\,2} + (2\ gh)}$$

$$= \sqrt{(8.2)^2 + (64.4 \times 6.95)}$$ ▷1

$$V = 22.8 \text{ fps}$$

$$Sh = 18.6 \times .5 = 9.3 \text{ ft}$$ (lateral horizontal displacement of vehicle)

APPROACH NO. 2

$$KE = (1/2) I\, w^2 = Wh$$

$$I_x = 33034 \text{ lb-in.-sec}^2 \text{(Roll)}$$

$$W_t = 8600 \text{ lb}$$

$$= 8600\ (12 \times 6.6) = 680{,}000 \text{ in.-lb}$$

$$h = 18.2 - 11.6 = 6.6$$

$$I_{xt} = I_x + (M_o\ d^2) = 33034 + \left[\frac{8600}{386} \times (42 \times 12^2)\right] =$$

$$= 33034 + (6{,}050{,}000) = 6.1\ (10^6)$$

I_{xt} refers to fulcrum point at 46 ft from CG

APPROACH NO. 2 (Cont'd)

$I_{xt} = 6.1 \; (10^6) \; \text{lb-in.-sec}^2$

$W = \sqrt{\frac{2.KE}{I}} = \sqrt{\frac{2 \times 680,000}{6.1 \; (10)^6}} = .48 \text{ rad/sec}$

$V_t = RW = (42 \times 12) \; .48 = 240 \text{ in./sec}$

V_t = Tangential Vel = 20 ft/sec

$V_v = V_t \; (\sin \;\;) = 240 \; (.405) = 8.1 \text{ ft/sec}$

$V_h = V_t \; (\cos \;\;) = 240 \; (.92) = 18.4 \text{ ft/sec}$

Assume that at ground the CG is 4.7 ft from the ground level.

The free vertical distance is: (11.6 - 4.7)

The final vertical velocity is:

$$V_{v4} = \sqrt{V_{v3}^2 + 2gh} = 22.6 \text{ ft/sec}$$ [1]

The time for the free-fall portion is:

$$t = \frac{S_v}{V_v \text{ avg.}} = .48 \text{ sec}$$

Assuming that the lateral (horizontal) velocity is constant, the lateral horizontal displacement of the body is:

$$S_h = V_{h_{3-4}} \; (t) = 18.4 \; (.48) = 8.9 \text{ ft}$$

[1] The vertical velocity stated in the test plan was based on expressing the final velocity as $\sqrt{2gh} + V^1$

V^1 = vertical velocity component at initiation of free fall

ANALYTICAL DATA

COMPUTER OUTPUT CORRELATION RUN

The results of the analysis using a 31-mass model to correlate with the drop test data are presented in the section in Volume I entitled CORRELATION. The following output plots representing a cross section of the time histories are presented in Figures 88 through 100:

Aft Fuselage Lateral Velocity
Forward Fuselage Lateral Velocity
Aft Fuselage Vertical Velocity
Forward Fuselage Vertical Velocity
Engine Lateral Acceleration
Transmission Rotor Housing Lateral Acceleration
Mid Fuselage Lateral Acceleration
Engine Vertical Acceleration
Transmission Rotor Housing Vertical Acceleration
Mid Fuselage Vertical Acceleration
Engine Mount Vertical Deflection
Transmission Mount Vertical Deflection
Forward Occupant Vertical Deflection

COMPARISON OF ANALYTICAL AND TEST RESULTS - AXIAL RESPONSES

Figures 101 through 106 show comparisons of analytical and test axial responses for the engine and transmission. Accelerations, velocities and displacements are presented. No attempt was made to obtain good correlation with the axial responses, since the objective was to obtain good correlation of a combined vertical-lateral drop. However, the acceleration results are still close to the right magnitude, although the analytical results appear to lag behind the test results by 30-50 milliseconds. The velocities and displacements show consistent trends, but the magnitudes are off. It is felt that the results shown are quite reasonable for a first approximation of the input data, and that acceptable correlation of the axial responses could be obtained with a little additional effort.

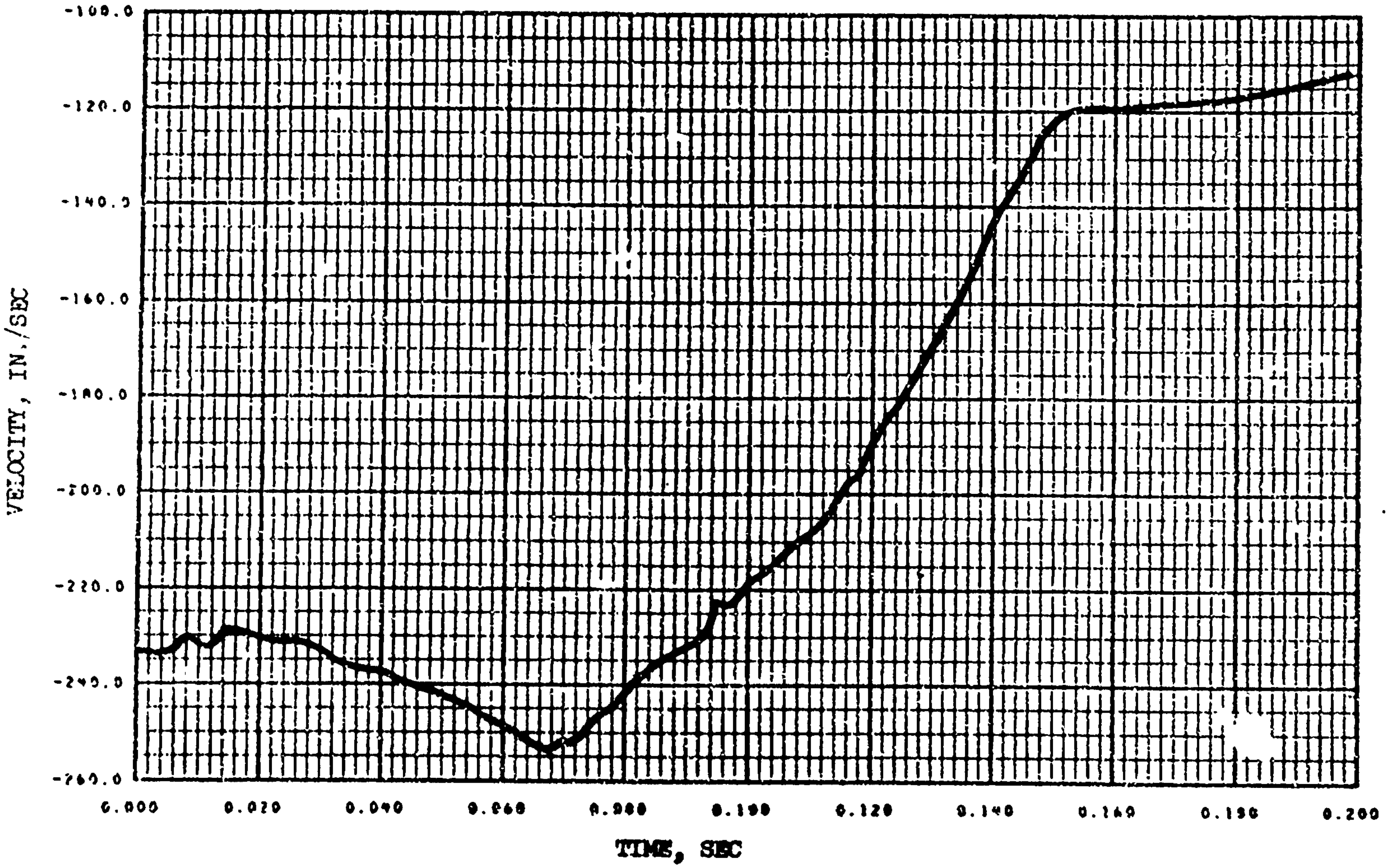


Figure 88. Correlation Run Analysis Output, Aft Floor, Lateral Velocity Time History.

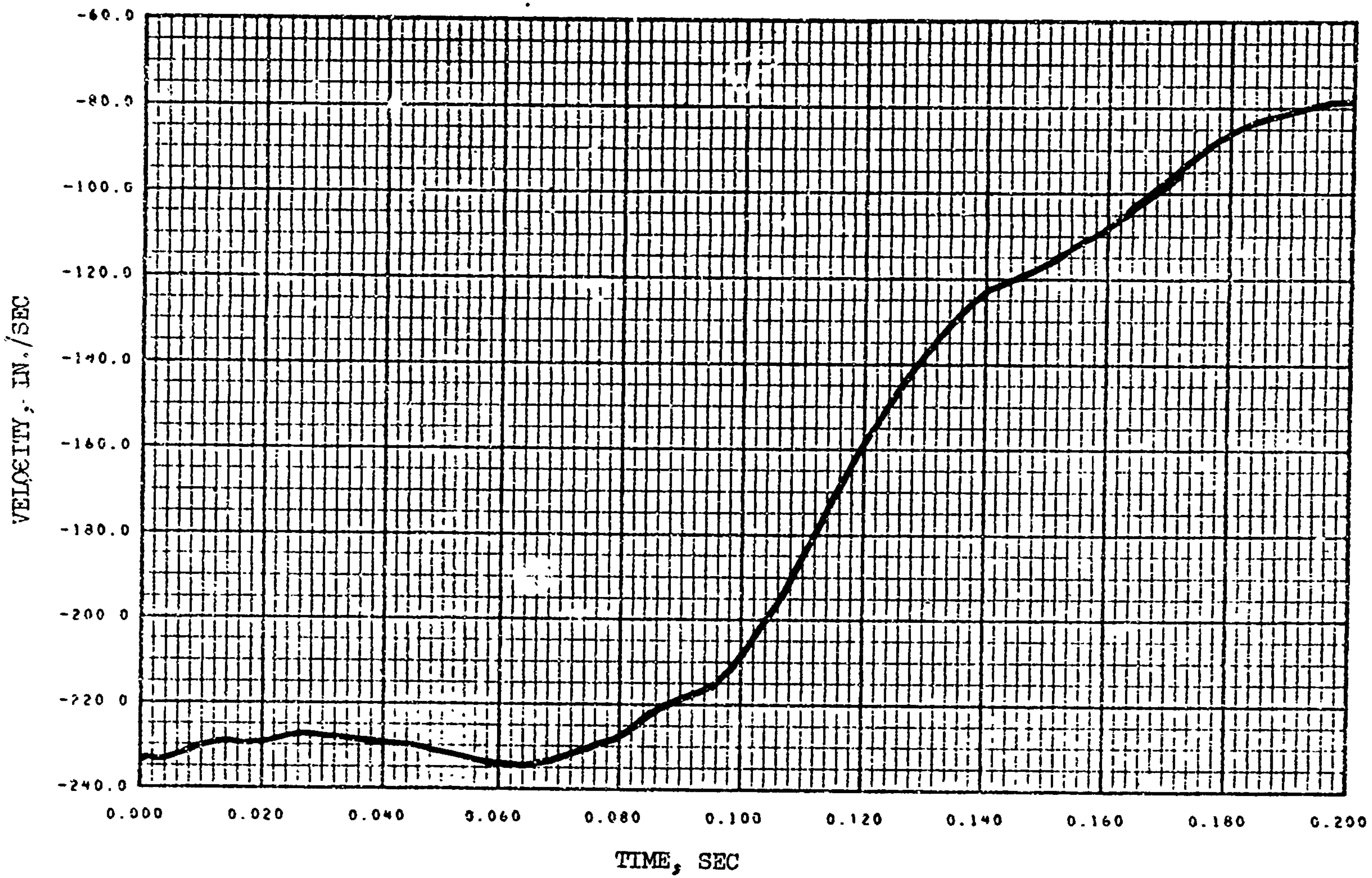


Figure 89. Correlation Run Analysis Output, Forward Floor, Lateral Velocity Time History.

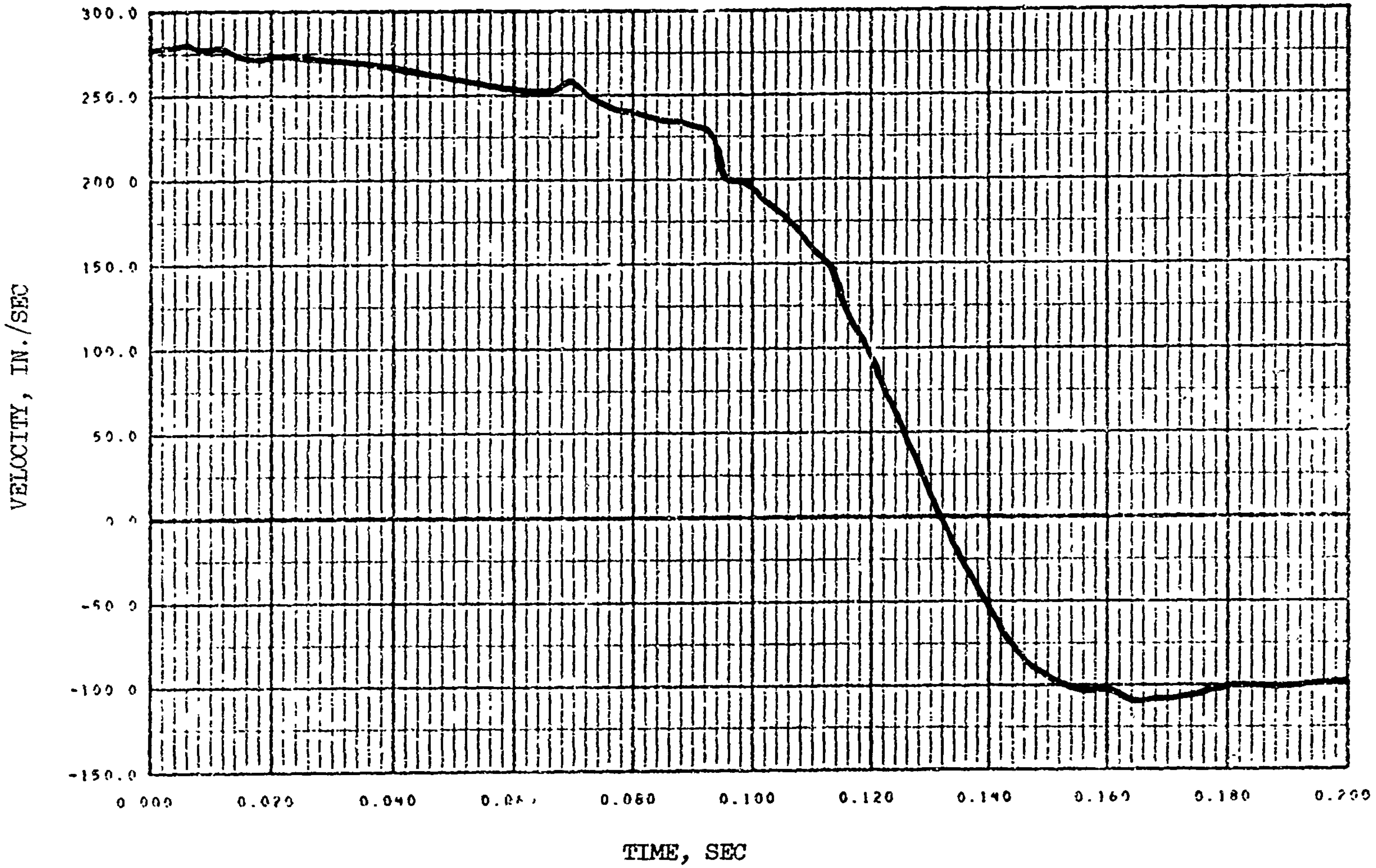


Figure 90. Correlation Run Analysis Output, Aft Floor, Vertical Velocity Time History.

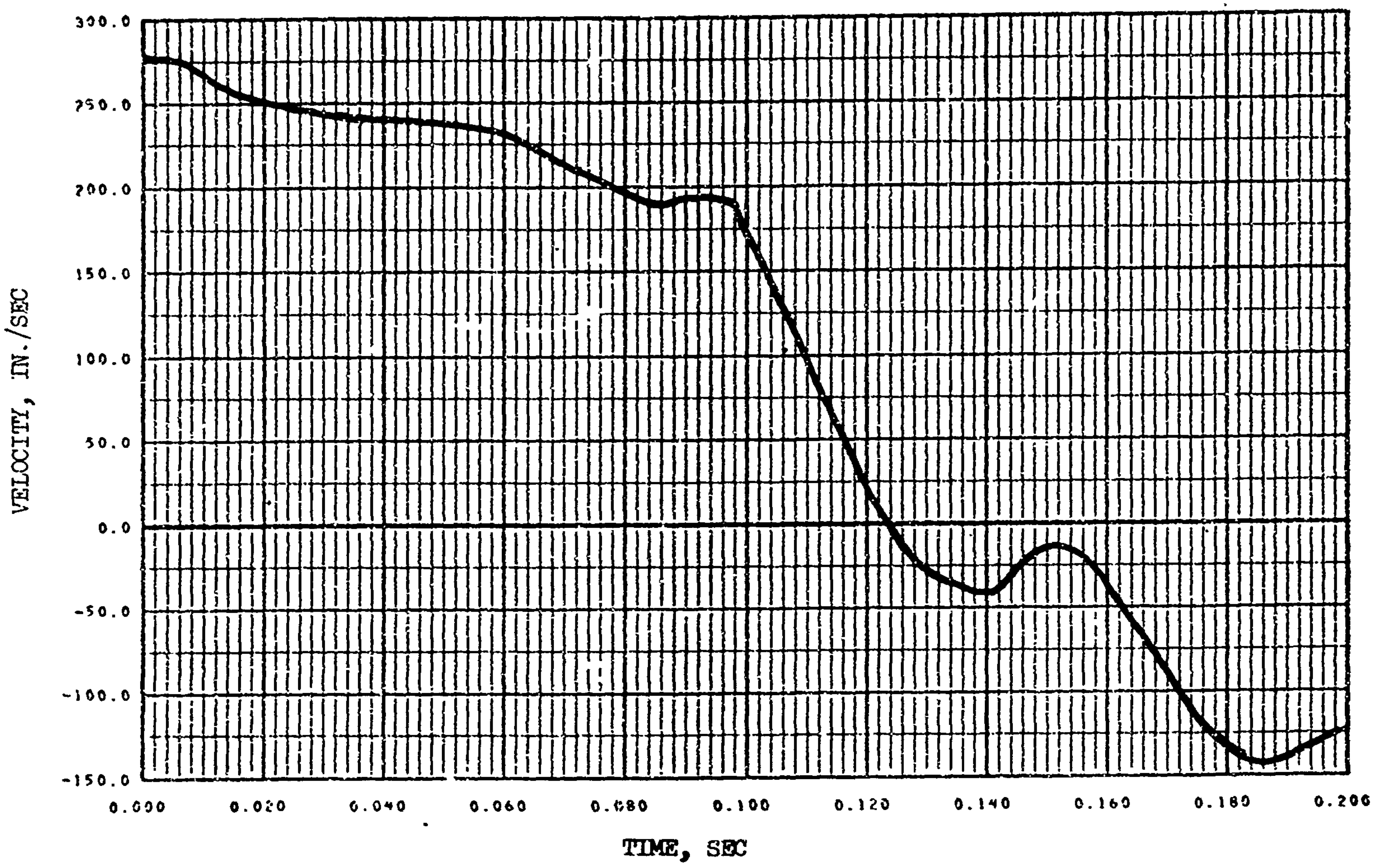


Figure 91. Correlation Run Analysis Output, Forward Floor, Vertical Velocity Time History.

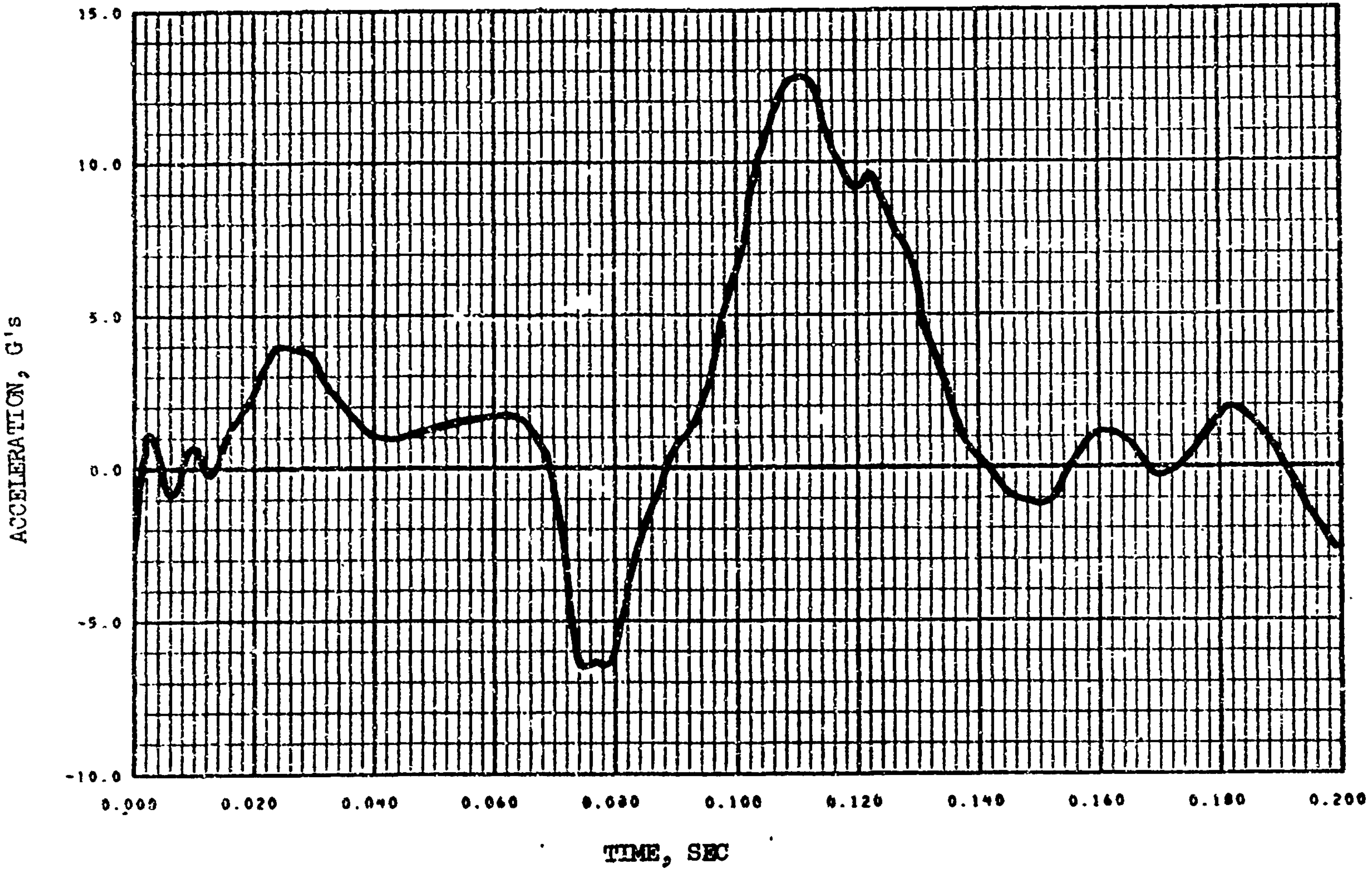


Figure 92. Correlation Run Analysis Output, Engine, Lateral Acceleration Time History.

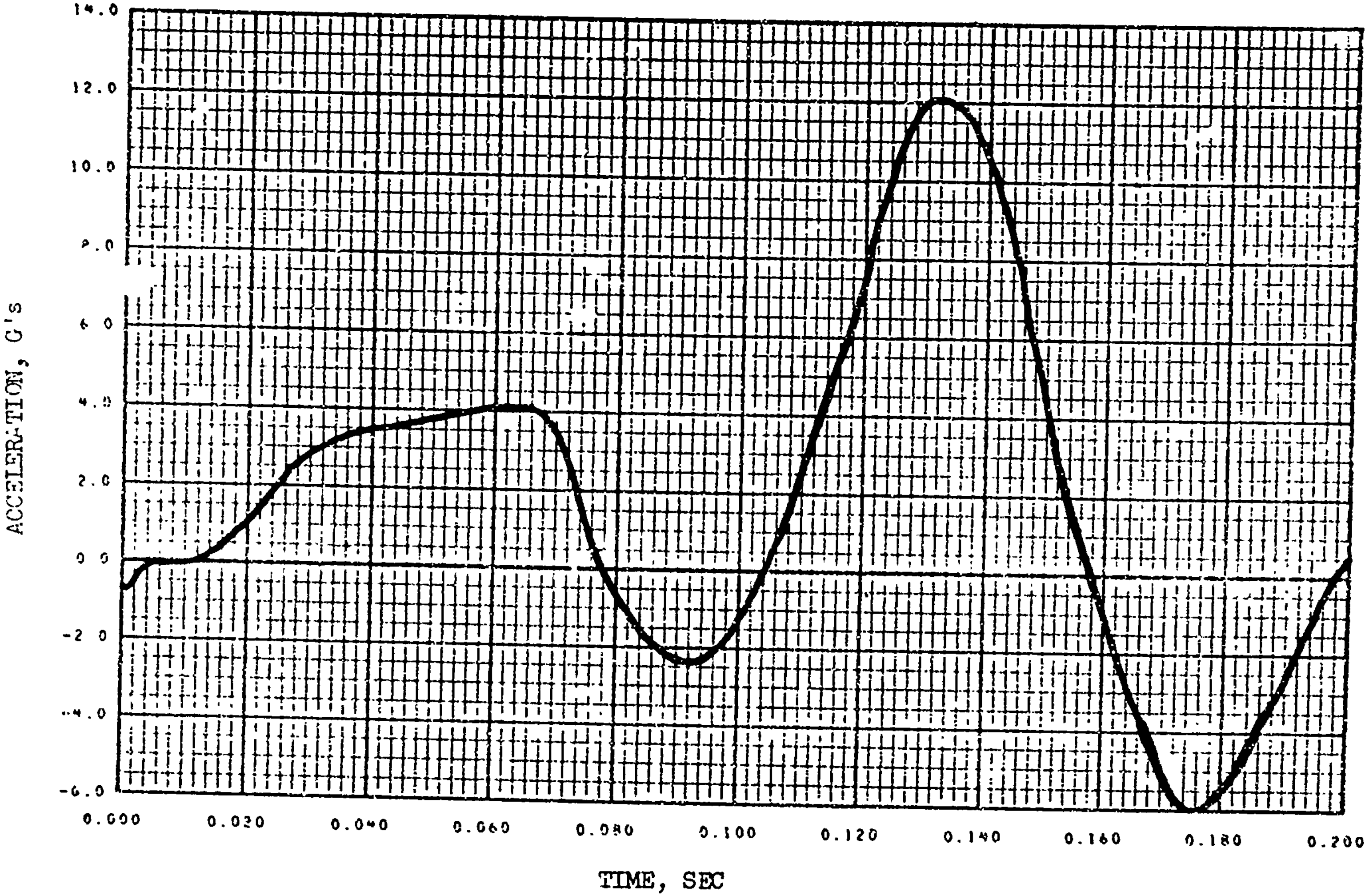


Figure 93. Correlation Run Analysis Output, Transmission Rotor Housing, Lateral Acceleration Time History.

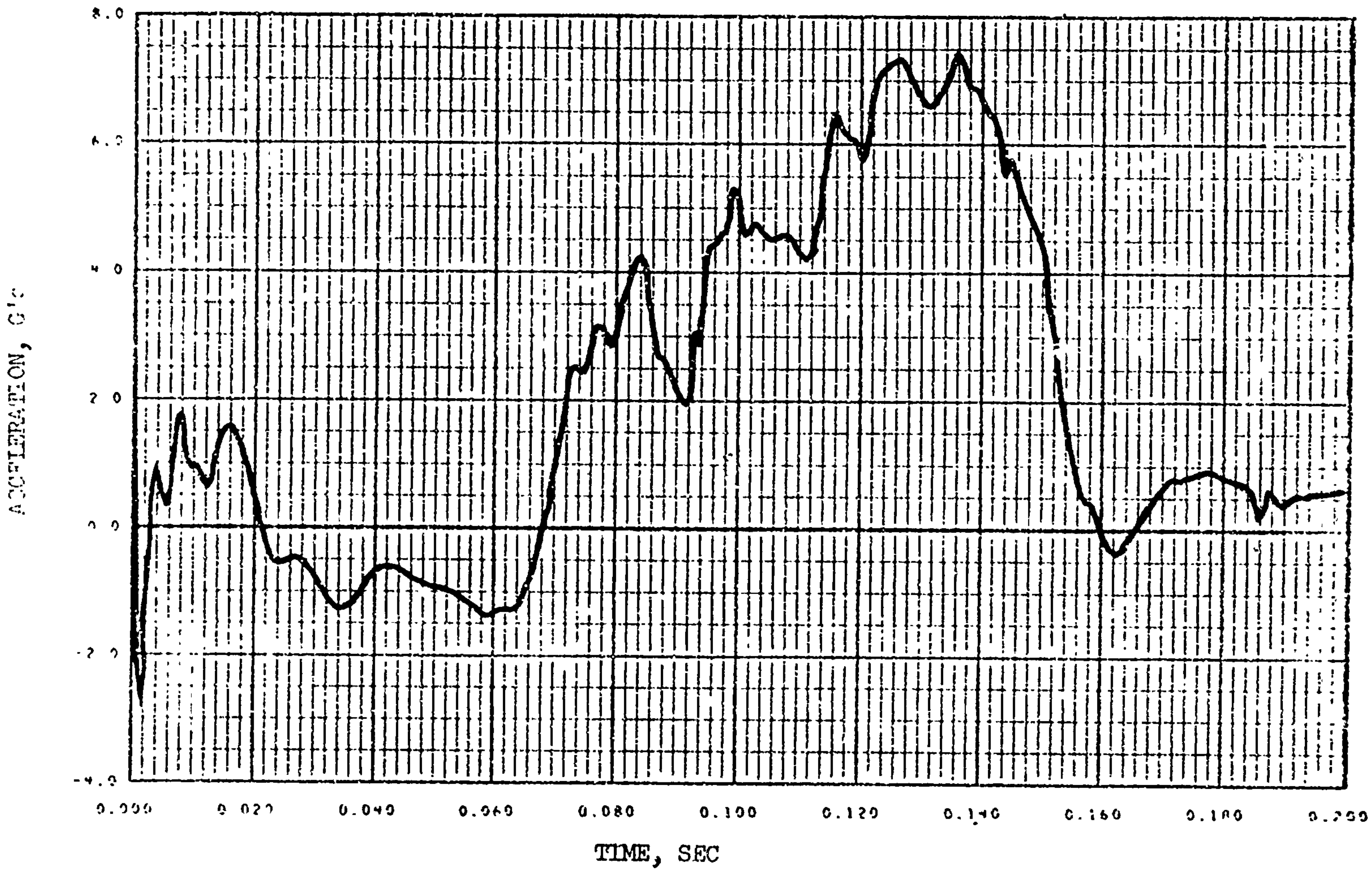


Figure 94. Correlation Run Analysis Output, Mid-Floor, Lateral Acceleration Time History.

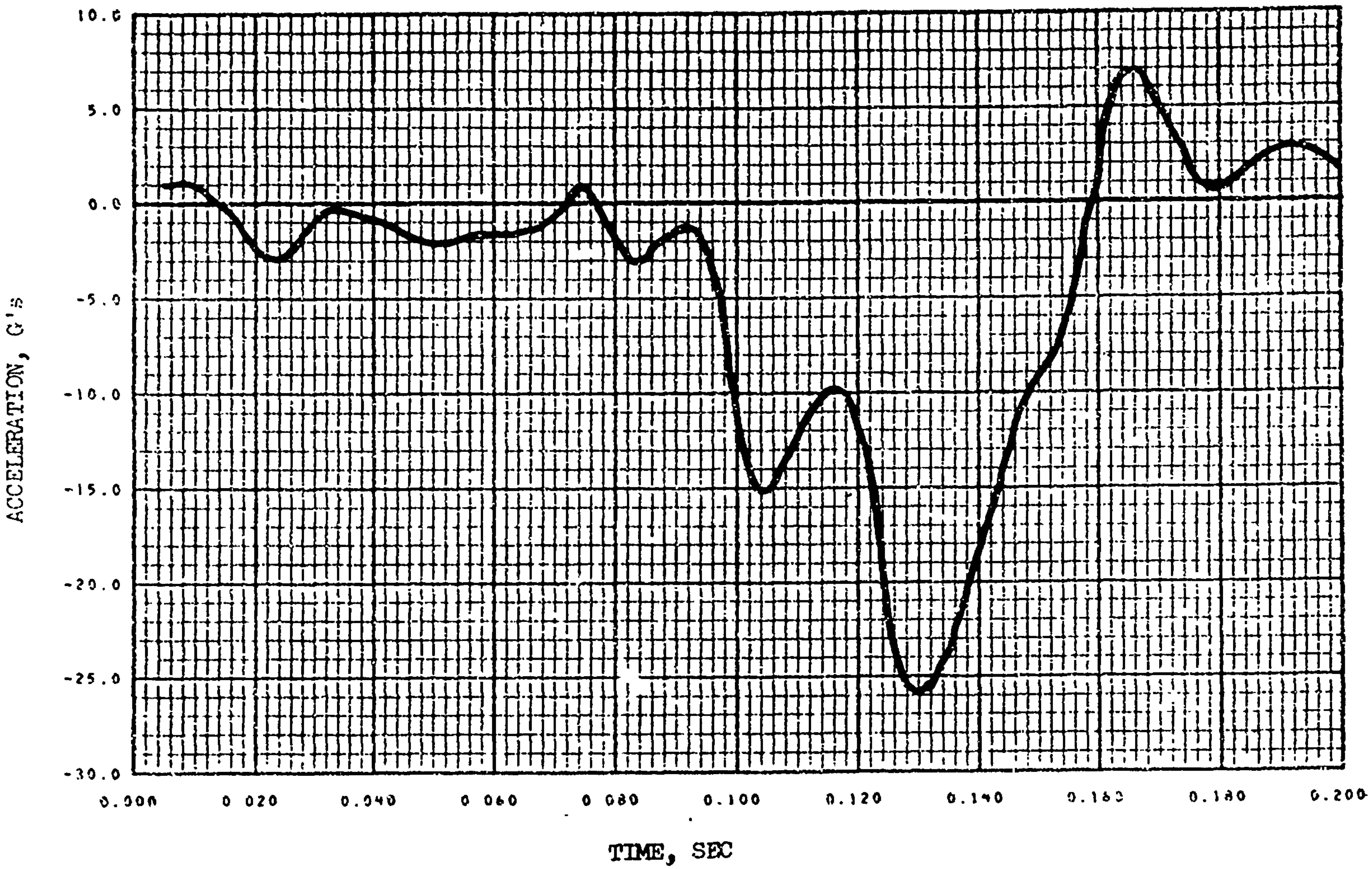


Figure 95. Correlation Run Analysis Output, Engine, Vertical Acceleration Time History.

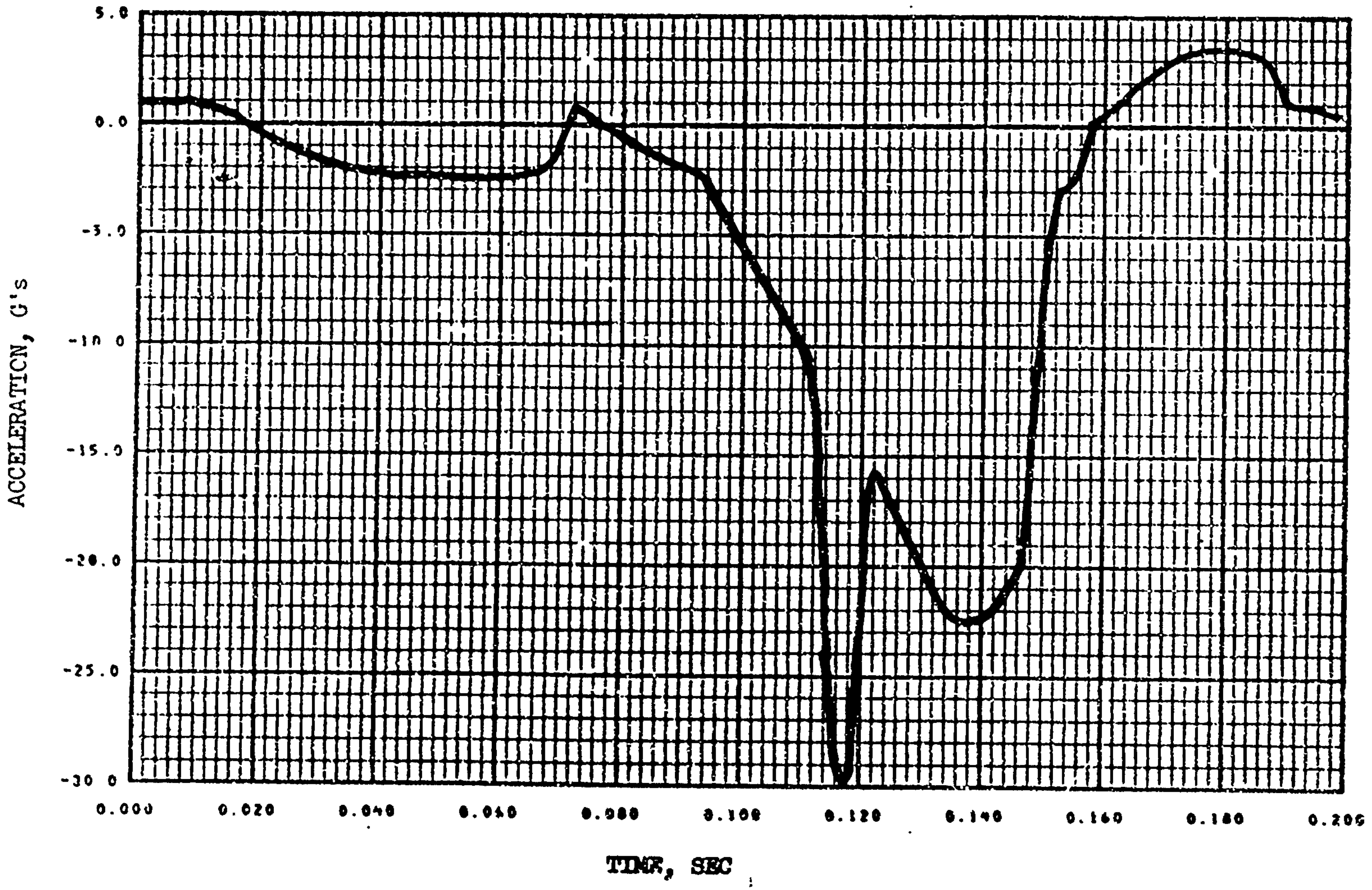


Figure 96. Correlation Run Analysis Output, Transmission Rotor Housing, Vertical Acceleration Time History.

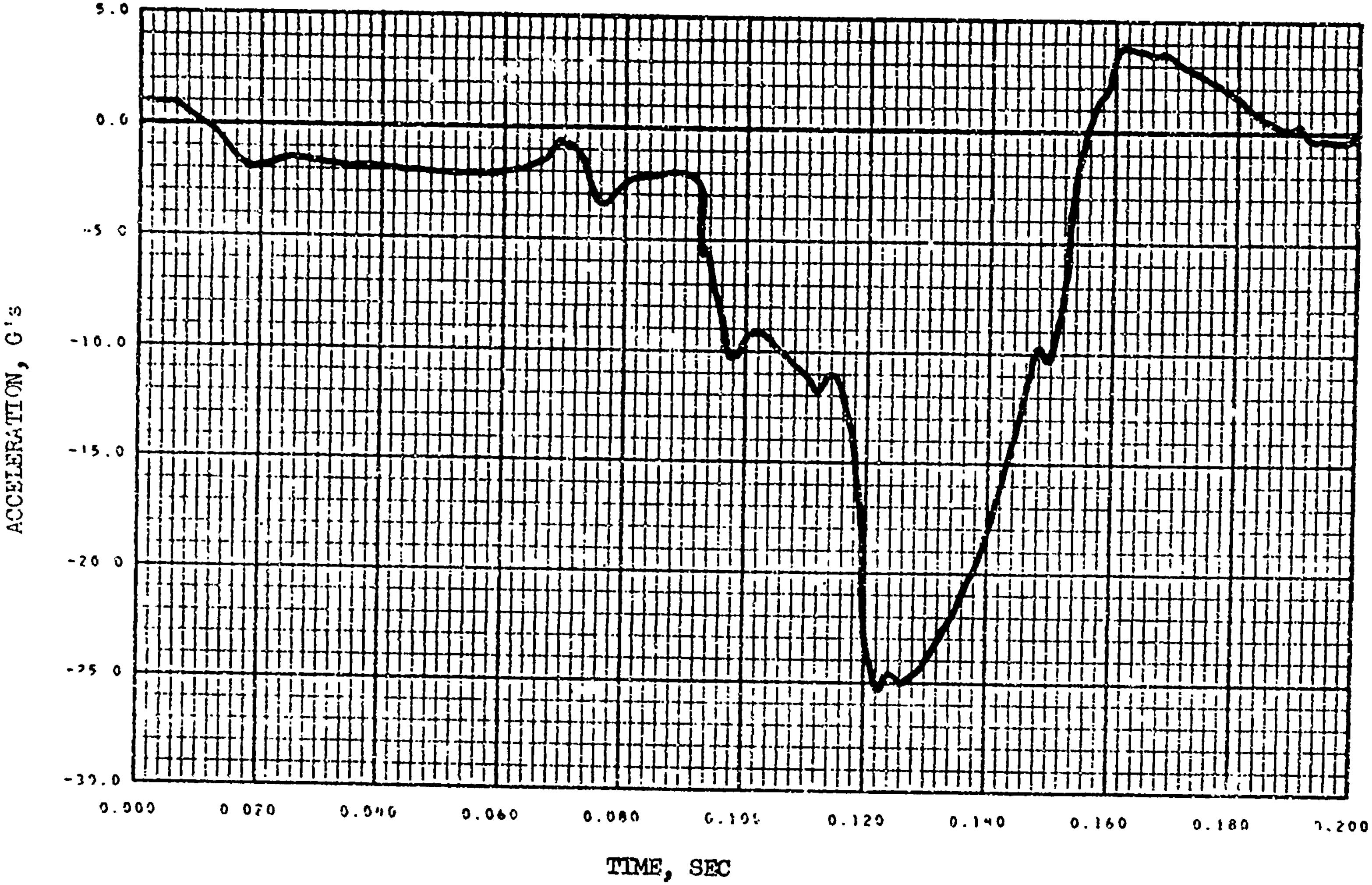


Figure 97. Correlation Run Analysis Output, Mid-Floor, Vertical Acceleration Time History.

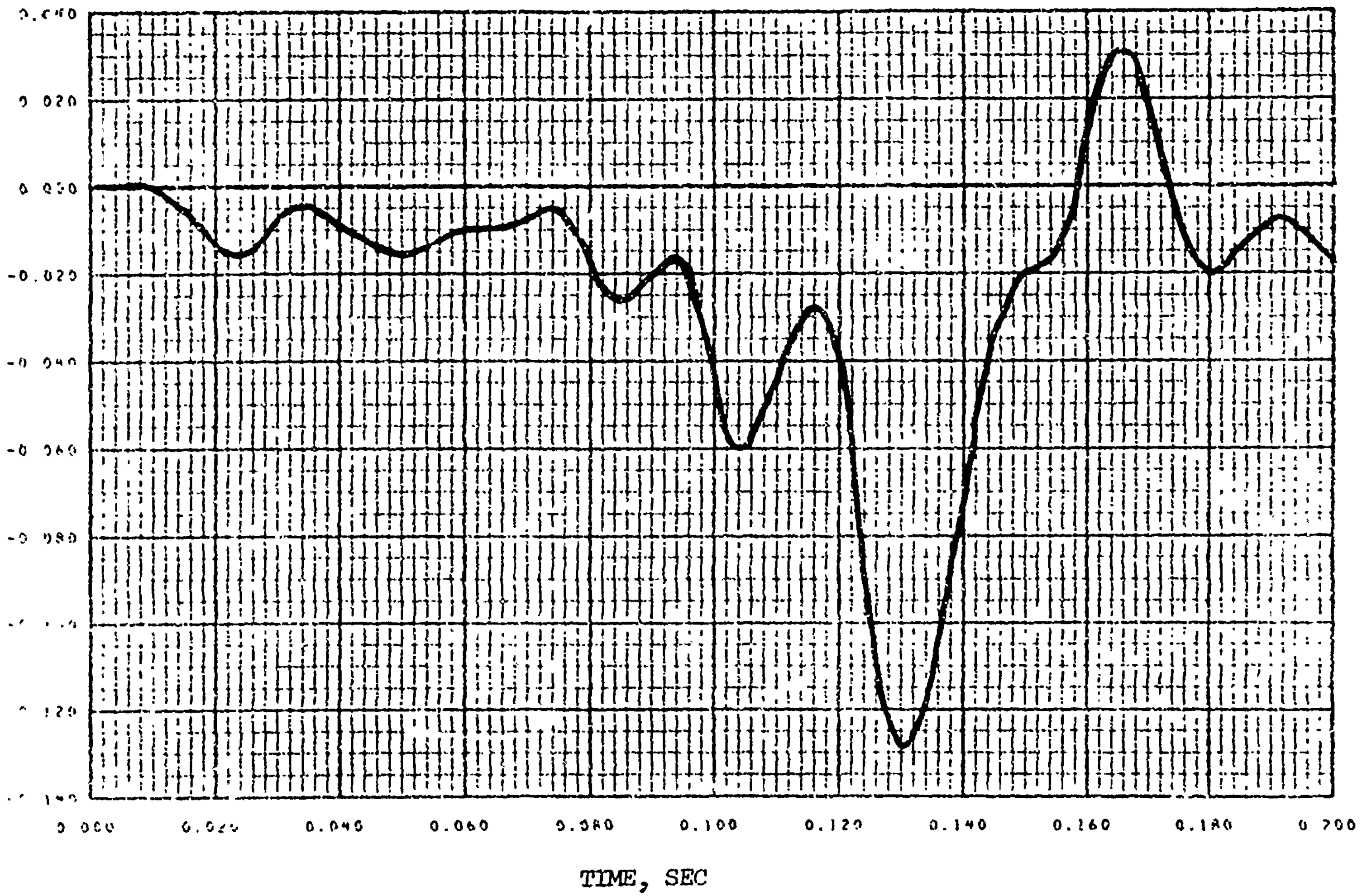


Figure 98. Correlation Run Analysis Output, Engine Mount, Vertical Deflection Time History.

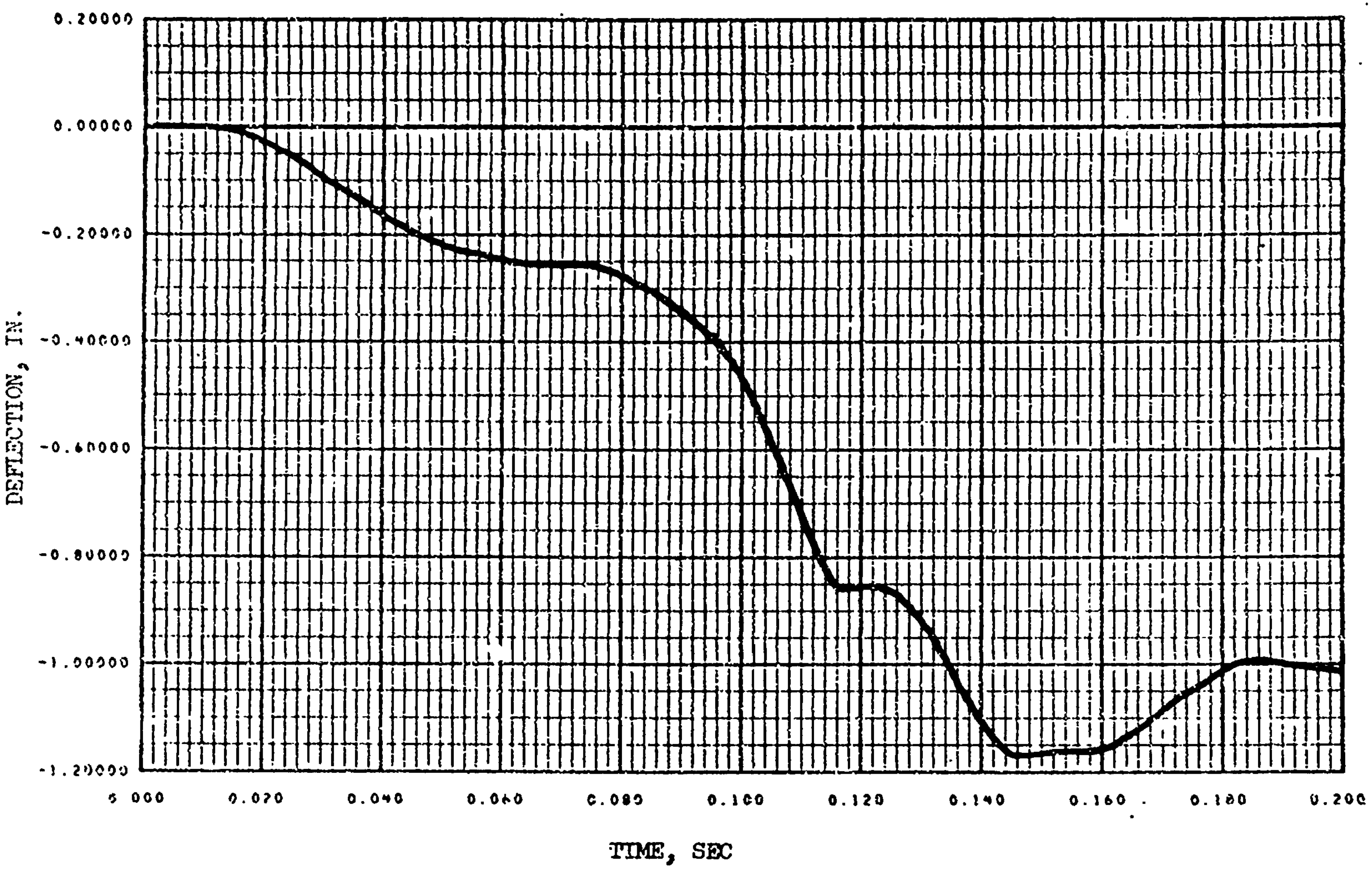


Figure 99. Correlation Run Analysis Output, Transmission Mount, Vertical Deflection Time History.

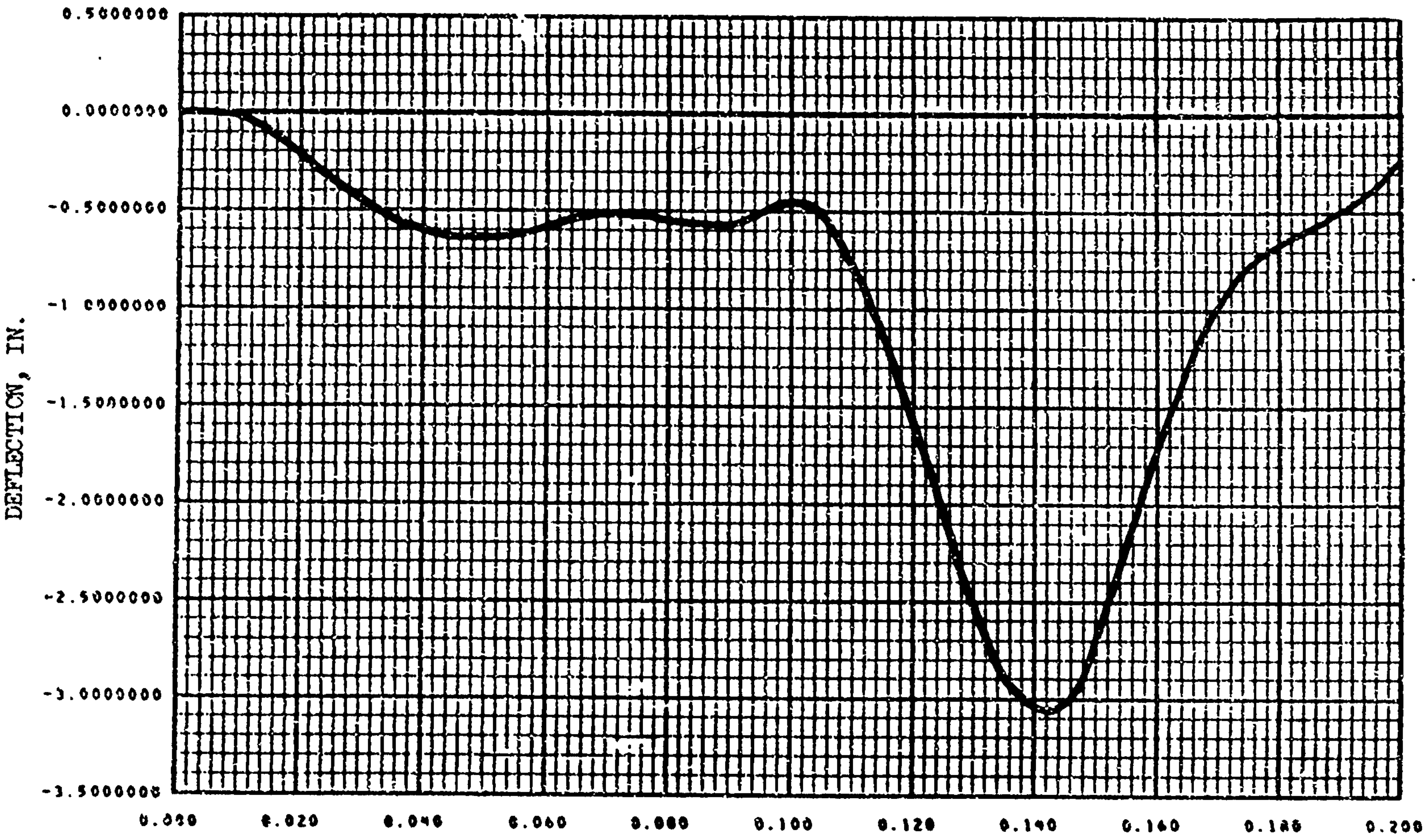


Figure 100. Correlation Run Analysis Output, Forward Seated Occupant, Vertical Deflection Time History.

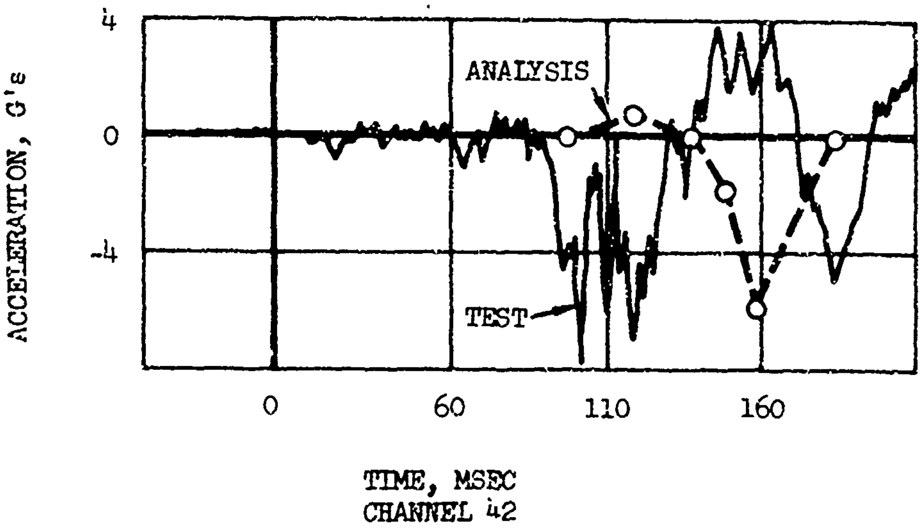


Figure 101. Correlation, Transmission Rotor Housing Axial Acceleration.

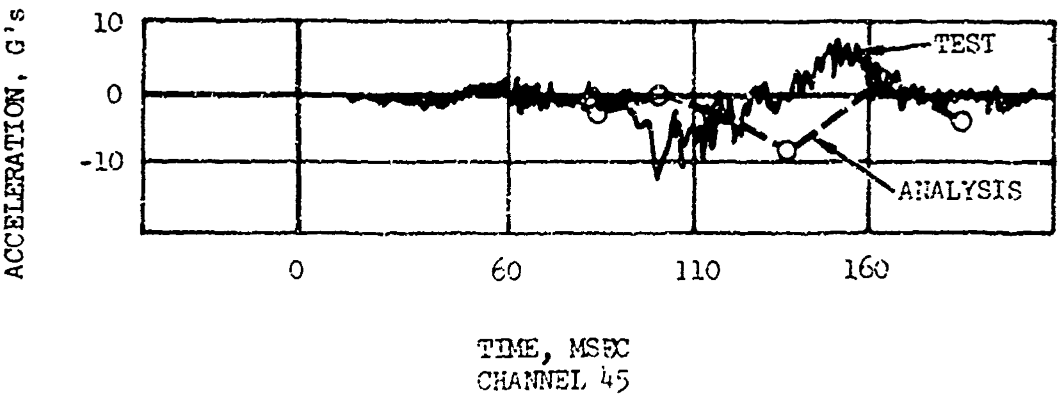


Figure 102. Correlation, Engine Axial Acceleration.

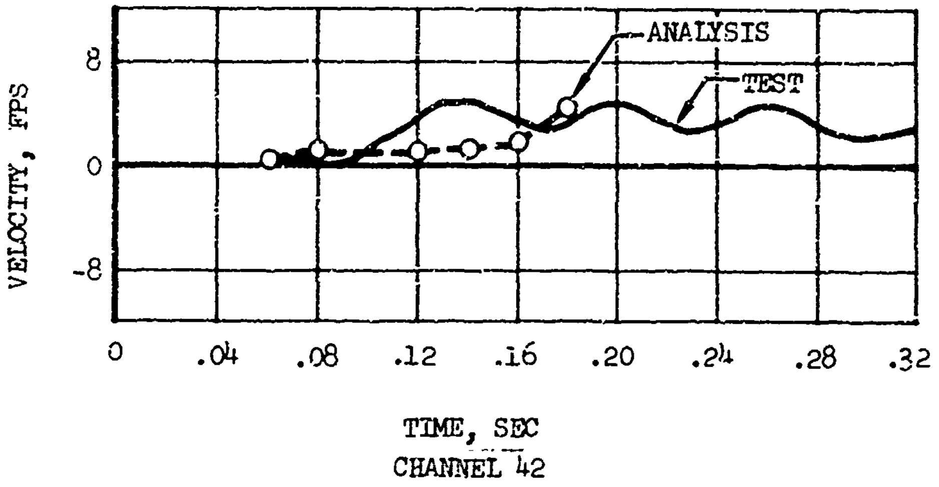


Figure 103. Correlation, Transmission Rotor Housing Axial Velocity.

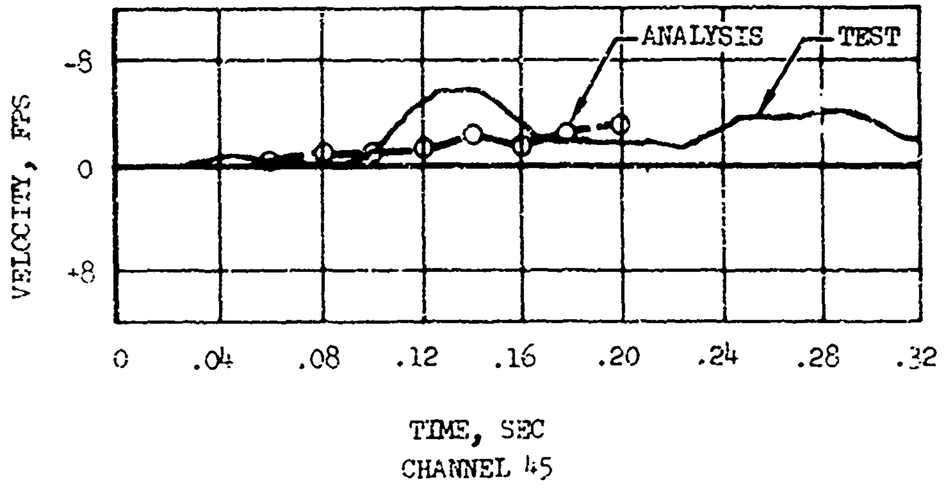


Figure 104. Correlation, Engine Axial Velocity.

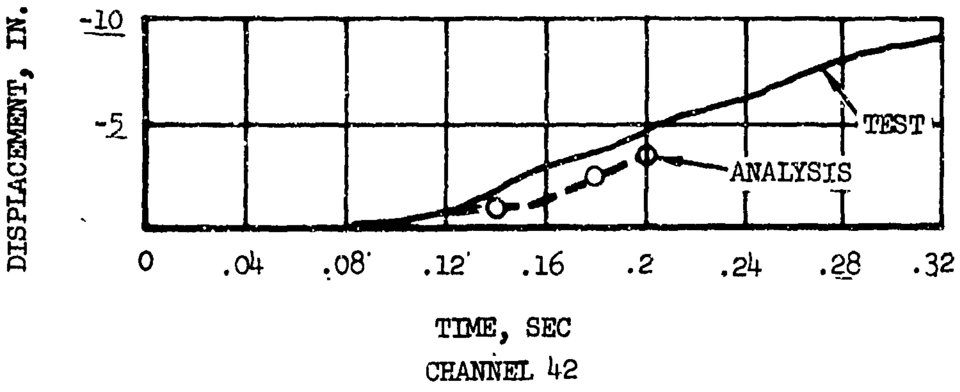


Figure 105. Correlation, Transmission Rotor Housing Axial Displacement.

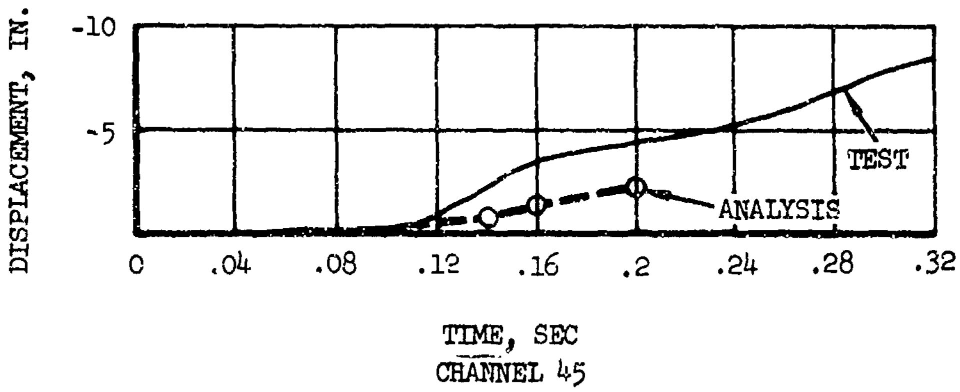


Figure 106. Correlation, Engine Axial Displacement.

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